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LETTERS ON CHEMISTRY.

FAMILIAR LETTERS

ON

CHEMISTRY,

IN ITS RELATIONS TO

PHYSIOLOGY, DIETETICS, AGRICULTURE, COMMERCE,
AND POLITICAL ECONOMY.

BY

JUSTUS VON LIEBIG.

THIRD EDITION, REVISED AND MUCH ENLARGED.

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TO

SIR JAMES CLARK, BART., M.D., F.R.S.

PHYSICIAN TO THE QUEEN AND HIS ROYAL HIGHNESS
PRINCE ALBERT, &c.

◆

MY DEAR SIR JAMES,

A MINISTER of the British Crown, in addressing the House of Commons, described the social state of your country in the following terms:—"We have shown the example of a nation, in which every class of society accepts with cheerfulness the lot which Providence has assigned to it; while at the same time every individual of each class is constantly striving to raise himself in the social scale,—not by injustice and wrong, not by violence and illegality; but by persevering good conduct, and by the steady and energetic exertion of the moral and intellectual faculties, with which his Creator has endowed him."* These words must have filled the heart of every Briton with feelings of pride, and with confidence in their Government. You, too, my dear Sir James, are one of those men who, impressed with a strong feeling of what is required for the progressive improvement of society, devote their powers to the welfare of their country. By your

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* Lord Palmerston's Speech, June 25th, 1850.

persevering exertions, aided by others entertaining similar views, and, supported by the patronage of an enlightened Prince, who sees in the advancement of science the nation's good, you have succeeded in establishing in your Metropolis an Institution—the Royal College of Chemistry—which affords ample opportunities, under an able teacher, to all who desire to become practically acquainted with the various departments of the science to which I have devoted my life, and in the progress of which the prosperity and happiness of nations is so intimately involved.

Allow me, whom you will scarcely consider a foreigner, since I am proud to be enabled to call myself a freeman of two of your most important cities—allow me, my dear Sir James, to express to you the thanks which Science owes you, by placing your name at the head of a work, the object of which is to make known to a wide circle the recent progress of Chemistry, and to explain the principles of natural science in some of their most important applications.

I remain, my dear Sir James,

Very sincerely yours,

JUSTUS VON LIEBIG.

PREFACE.

In preparing a new edition of my "Letters on Chemistry," I was induced to prefix a series of letters on the origin and development of chemical science. With this view, I availed myself chiefly of the excellent work of Dr. H. Kopp, on the "History of Chemistry," of Sprengel's "History of Medicine," and of Dr. Carrière's "View of the Philosophical State of the World at the period of the Reformation." *

I have also made large additions, in the shape of new letters, containing the results of my researches, during the last few years, in Agricultural and Physiological Chemistry. The subject of Dietetics has received particular attention. The Analyses adduced have been, for the most part, made under my own eyes, by some able young chemists—Messrs. Porter and Johnson, of New York; Zedeler, of Copenhagen; Lehmann, of Dresden; Keller, of

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* "Die Philosophische Weltanschauung der Reformationszeit."

Würzburg; Stammer, of Luxemburg; Arzbächer, Buchner, and Kekulé, of Darmstadt; Dr. Henneberg, and Professor Griepenkerl, of Goettingen; and my assistants, Drs. Strecker and Fleitmann. To these gentlemen I now offer my warmest thanks, for the assistance which they afforded me.

My friend, Dr. Gregory, has, at my request, undertaken to edit these letters; and, from his intimate familiarity with chemical science, and more especially with the physiological subjects here treated of, I am confident that the task could not have been intrusted to better hands.

JUSTUS VON LIEBIG.

Giessen, *May* 14*th*, 1851.

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APPENDIX.

ERRATA.

Page 90, line 4, *for* "carbonic acid" *read* "carbonic oxide."
Page 111, line 18, *for* "peroxide of manganese" *read* "sesquioxide of manganese."
Page 121, line 24, *for* "with the aid" *read* "without the aid."
Page 147, line 4 from bottom, *for* "sulphate of lead" *read* "sulphuret of lead."
Page 301, line 11 from bottom, *for* "ancient" *read* "recent."
Page 307, line 2 from bottom, *for* "cause" *read* "case."
Page 308, line 2, *for* "causes" *read* "cases."

LETTERS ON CHEMISTRY.

LETTER I.

CHEMISTRY is so often alluded to in modern writings, that it may perhaps be regarded as a problem of some importance to indicate more specially the influence of this science on the useful arts and on industry, as well as its relations to agriculture, physiology, and medicine.

I would desire, in the first section, to establish the conviction, that Chemistry, as an independent science, offers one of the most powerful means towards the attainment of a higher mental cultivation; that the study of Chemistry is profitable, not only inasmuch as it promotes the material interests of mankind, but also because it furnishes us with insight into those wonders of creation which immediately surround us, and with which our existence, life, and development, are most closely connected.

It is so congenial to the ever-active human intellect to inquire into the causes of natural phenomena, and into the changes which we daily observe in all that surrounds us, that those sciences which give satisfactory answers to our inquiries exercise more influence on the progress of mental cultivation than any others.

Chemistry, as a part of the science of Natural Philosophy, is most intimately connected with physics; and this latter science is as closely related to astronomy and to mathematics. The simple observation of nature forms the foundation of every branch of natural science, and observation has only very gradually assumed the form of science. Thus the relations of light to the earth, the succession of day and night, and the variations of the seasons, gave birth to *astronomy*.

As the human mind advances in knowledge, from whatever source that knowledge may be derived, all its powers are strengthened and elevated; and its progress in all other directions thus promoted. The exact knowledge of the relation connecting certain phenomena, the acquisition of a new truth, is equivalent to a new sense, enabling us now to perceive and recognise innumerable phenomena, which remain invisible or concealed to others, as they formerly were to ourselves.

In the progressive growth of astronomy, physics or mechanical science was developed, and when this had been, to a certain degree, successfully cultivated, it gave birth to the science of chemistry. And now we may anticipate that from ORGANIC CHEMISTRY the laws of life—the science of physiology—will be developed.

But it must not be forgotten that our predecessors determined the duration of the year, explained the changes of the seasons, and calculated eclipses of the moon, without any acquaintance with the laws of gravitation; that people have built mills and constructed pumps without knowing anything of atmospheric pressure; that glass and porcelain were manufactured, stuffs dyed, and metals separated from their ores by mere empirical processes of art, and without the guidance of correct scientific principles. Even geometry had its foundation laid in experiments and observations; most of its theorems had been seen in practical examples, before the science was established by abstract reasoning. Thus, that the square of the hypothenuse of a right-angled triangle is equal to the sum of the squares of the other two sides, was an experimental discovery, else why did the discoverer sacrifice a hetacomb when he made out its *demonstration?*

How different now is the aspect of the discoveries of the naturalist, since the inspiration of a true philosophy, whether it be called physics, chemistry, mathematics, or any other science, has led him to investigate phenomena in order to draw conclusions as to their *causes* and the *laws* which regulate them. From one sublime genius—from NEWTON—more light has proceeded than the labour of a thousand years preceding had been able to produce. The true theory of the movements of the heavenly bodies, the law which regulates the fall of bodies, *i. e.* gravitation, has become the parent of innumerable other discoveries. Navigation, and, in consequence, commerce and industry, nay, every individual of our species has derived, and will continue to derive, as long as mankind exists, incalculable benefits, both intellectual and material, from his discoveries.

Without an acquaintance with the history of physics it is impossible to form any correct opinion of the effect which the study of nature has exercised upon the cultivation of the mind. In our schools mere children are now taught truths, the attainment of which has cost immense labour and indescribable efforts. They smile when we tell them that an Italian philosopher wrote an elaborate treatise to prove that the snow found upon Mount Ætna consists of the same substance as the snow upon the Alps of Switzerland, and that he heaped proof upon proof that both these snows, when melted, yielded water possessed of the same properties. And yet this conclusion was really

^ Chemistry has shown still more curious results, & many which have been turned to great account. It is the handmaid, & promoter of many other sciences. 48

not so very palpable, since the temperature of the two climates so widely differ, and no one in those days had any notion of the diffusion of heat over the surface of the earth. When a schoolboy takes a glassful of liquid, and, placing a loose piece of paper over it, inverts the glass without spilling a drop of its contents, he only astonishes another child by his performance, and yet this is the identical experiment which renders the name of Torricelli immortal. It is a variation of that experiment with which the burgomaster of Magdeburg (Otto von Guericke) threw the Emperor and the princes of the empire at Ratisbon into speechless astonishment. Our children have more correct notions of nature and natural phenomena than had Plato! they may treat with ridicule the errors which Pliny has committed in his Natural History!

By the study of history, of philosophy, and of the classics, we obtain a knowledge of the intellectual world, the laws of thought, of mental inquiry, and of the spiritual nature of man. Whilst we hold communion with the spirits of the great and good of all ages, we derive from the experience of past centuries the power of soothing and governing the passions, and of softening the heart: we are enabled to comprehend man as he exists at the present time, since his moral nature remains ever the same. We are taught to embellish, and present, in the most engaging form, the principles of truth, of justice, and of religion, and thus to make the most enduring impression upon the minds of others. History and philosophy, however, could not prevent men from burning their fellow-creatures for witchcraft. For when the great Kepler went to Tubingen to save his mother from the stake, he succeeded only by proving that she possessed none of the characteristic signs essential to a witch!

Only about seventy years ago was chemistry, like a grain of seed from a ripe fruit, separated from the other physical sciences. With Black, Cavendish, and Priestley, its new era began. Medicine, pharmacy, and the useful arts, had prepared the soil upon which this seed was to germinate and to flourish.

The foundation of the science is, as is well known, an apparently very simple theory of the phenomena of combustion. We have now experienced the great benefits and blessings which have sprung and been diffused from this view. Since the discovery of *oxygen* the civilised world has undergone a revolution in manners and customs. The knowledge of the composition of the atmosphere, of the solid crust of the earth, of water, and of their influence upon the life of plants and animals, was linked with that discovery. The successful pursuit of innumerable trades and manufactures, the profitable separation of metals from their ores, also stand in the closest connection therewith. It may well be said that the material prosperity of empires has increased many-fold since the time oxygen became known, and the fortune of every individual has been augmented in proportion. Every discovery in chemistry has a tendency to bring forth similar fruits. Every application of its laws is capable of producing advantages to the state in some way or other, augmenting its powers, or promoting its welfare.

In many respects chemistry is analogous to mathematics. On the one hand, this latter science teaches us to measure land, to erect buildings, and to raise weights, and, like arithmetic, it is an instrument, the skilful employment of which secures most obvious and universal advantages ; on the other hand, mathematics enable us to draw correct logical conclusions according to definite rules, teach us a peculiar language, which allows us to express a series of such conclusions in the most simple manner, by lines and symbols intelligible to every one who knows this language; give us the power to deduce truths by means of certain operations with these lines and symbols; and furnish us with an insight into relations of things formerly obscure or unknown to us. The mechanician, the natural philosopher, the astronomer, employ mathematics as an indispensable instrument for the attainment of their ends. They must, indeed, be so practised in its management that its application becomes a mechanical habit, requiring only the exercise of memory. But it is not the mere instrument which plans and executes the work, but the human intellect. It is obvious, that without the power of observation, without sagacity, all mathematical knowledge is useless. We may imagine a man who, favoured by a good memory, has rendered himself intimately acquainted with every theorem of mathematics, who has obtained an eminent degree of skilfulness in handling this instrument, but who is altogether unable to invent a problem for solution. If we propose to him a problem, and thus give him the conditions for the solution of a question, he will succeed in obtaining an answer by performing the current operations with which he is familiar, and express it in a formula consisting of certain symbols, the meaning of which, however, is perfectly unintelligible to him, because he is deficient in other attainments essential for judging of its truth. Such a man is a mere calculating machine. But as soon as he possesses the capacity and the talent of proposing a question to himself, and testing the truth of his calculations by experiment, he becomes qualified to investigate nature. For from whence should he derive his problems if not from nature or from life? He is denominated a mechanician, an astronomer, or a natural philosopher, if, starting from observation, he is able to ascertain the connection of certain phenomena and the causes producing them; and then is capable, not merely of expressing the results in a ormula, in the language of the mathematician, but of making an application thereof, reproducing his formula in the shape of a phenomenon or external fact, thereby testing its truth. The astronomer, the mechanician, the natural philosopher, therefore, in addition to mathematics, which they use only as an instrument, must possess the art of observing and interpreting phenomena, and the ability to present the results of abstract reasoning in a visible shape by means of a machine or some form of apparatus ; in fact, to prove the correctness of their conclusions by experiment. The natural philosopher proposes to himself the solution of a problem,—he endeavours to ascertain the causes of a given phenomenon, the variations it undergoes, and the conditions under which these changes take place. If his questions have been correctly put, and all the circumstances (the factors) taken into account, he succeeds in obtaining, by the aid of mathematical processes, a simple expression for the unknown quantity or relation which has been the object of his search. This expression or formula, translated into ordinary language, explains the mutual connection of the observed phenomena, or of the experiments which he has instituted; and the formula is correct when it enables him to produce a certain series of new phenomena which are deductions from it.

It is easy to perceive how the mathematics stand connected with the study of nature ; and that, besides mathematics, a high degree of imagination, acuteness, and talent for observation, are required to make useful discoveries in astronomy and other physical sciences. It is a vulgar fallacy to ascribe discoveries to mathematics. It happens here, as in a thousand other cases, that the effect is confounded with the cause. Thus, effects are often ascribed to the steam-engine, which are properly due to fire, to coals, or to the human intellect. In order to make discoveries in mathematics, the same mental vigour, the same acuteness, the same power of thought are necessary, as are essential to the solution of the other different problems. Such discoveries in mathematics are the successive steps towards the perfection of the instrument, by which it is rendered capable of innumerable useful applications, but the instrument alone makes no discoveries in natural science. It makes use of data furnished to it, of facts observed by the senses, and of ideas created by the mind. Experimental natural philosophy stands in this sense in contrast with mathematical natural philosophy. It is the former which discovers, examines, and prepares facts for the mathematician. The task of experimental physics is to express the laws, the general truths deduced, in the form of phenomena, to illustrate the mathematical formulæ by experiments, to make them manifest to the senses.

Chemistry, ~~in~~ answering her own questions, proceeds ~~in the~~ same manner as experimental physics. ~~She~~ teaches the methods of discovering and determining the qualities of the various substances of which the crust of the earth is composed, and which form the constituents of animal and vegetable organisms. We study the properties of bodies, and the alterations they undergo in contact with others. All our observations, taken collectively, form a language. Every property, every alteration which we perceive in bodies, is a word in that language. Certain definite relations are manifested in the deportment of bodies toward each other; we observe a similarity of form, or analogy of properties, or diversities in both respects. Such diversities are as numerous and various as the words of the most copious language, and they are no less varied in their signification and in the relations which they bear to our senses.

Bodies differ in quality; the meaning conveyed to us by their properties,—to pursue the illustration,—

changes according to the mode in which these elements are arranged. As in all other languages, so we have in that language in which material bodies hold converse with us, articles, substantives, and verbs, with their variations of cases, declensions, and conjugations. We have also many synonymes ; the same quantities of the same elements produce a poison, a remedy, or an aliment, a volatile or a fixed body, according to their manner of arrangement.

We know the signification of the properties of bodies, that is, of the letters and words in which nature speaks to us, and we use the alphabet to decipher and to read them ; as, for instance, a fountain of mineral water in Savoy cures that remarkable enlargement of the thyroid gland denominated goître, —I put certain questions to that water, the combination of the several letters in its answers informs me that it contains *iodine*. A man, having partaken of some food, dies soon after, with all the symptoms of poisoning. The language of phenomena, with which the chemist is familiar, tells him that arsenic, or corrosive sublimate, or some other body, was the cause of death.

The chemist, by his questions, compels a mineral to speak, to disclose its composition ; it tells him that it contains sulphur, iron, chromium, silica, alumina, or any other word of the chemical language of phenomena, arranged in a certain order. This is CHEMICAL ANALYSIS.

Then, again, the language of phenomena leads the chemist to new combinations, from which he derives innumerable useful truths that are applicable to the improvement of manufactures and arts, to the preparation of remedies, and to metallurgy. He has succeeded in deciphering the word *ultramarine*. The next step is to construct this word in a tangible form, to reproduce ultramarine with all its properties. This is APPLIED CHEMISTRY.

Hitherto scarcely any demand has been made upon the science of chemistry, by arts, manufactures, or physiology, which has not been responded to. Every question, clearly and definitely put, has been satisfactorily answered. Only when the inquirer had no precise idea of the problem to be solved has he remained unsatisfied.

The last and most elevated object of chemistry is the investigation of the causes of natural phenomena, of their variations, and of those factors which are common to different series of phenomena. The chemist ascertains the laws which regulate natural phenomena, and by combining together all that is observable and has been observed by the senses, he at last attains to a general intellectual expression for the phenomena,—in other words, to a THEORY.

But to enable us to read the book of nature, to understand its language, to perceive the truth of the theories of the philosopher, to subject to our will, and examine at our pleasure, the phenomena upon which a theory is based, and the powers producing them, we must necessarily learn the alphabet of the language, we must become familiar with the use of the signs or symbols employed, and by practice acquire skill in their management, and a knowledge of the laws which regulate their combinations. As in the higher branches of physics it is indispensable that the philosopher should have attained considerable practical skill in *mathematical analysis*, so the chemist, before he can investigate natural truths successfully, must have the most perfect knowledge of *chemical analysis*—he must be able to express all his conclusions—all his results—in the form of phenomena. Every experiment is a thought thus rendered perceptible to the senses. In order to prove or disprove our conclusions we have recourse to experiments, to the interpretation of phenomena at will.

There was a time when chemistry, in common with astronomy and all the physical sciences, was nothing more than an art, founded on empirical practice, subject only to rules discovered by experience; but since the causes of the changes in bodies which it effects, and their laws, *i. e.* the reasons of its rules, have become known, the empiric art has lost its value and importance. The acquisition of skill in manipulation by laborious and long-continued application, the tedious methods and endless precautionary measures formerly necessary to success in chemical manufactures, have become wholly needless since a correct knowledge of causes has been obtained. The strange apparatus and utensils of the chemist of former ages, their stoves and stills, are now mere matters of curiosity. The success of an experiment, or of a process, depends far less upon mechanical skill, than upon knowledge. Failure is the result of ignorance, and discoveries are made, not by manual dexterity, but by skill in combination, and by that intellectual power which creates new thoughts.

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In our lecture-rooms we teach the letters of the alphabet; in our laboratory their use. It is in the latter that the student acquires a readiness in reading the language of phenomena, that opportunities are furnished to him of learning the rules of combinations, of applying them, and of gaining a ready dexterity in their application. As soon as these signs, letters, and words have become formed into an intellectual language, there is no longer any danger of their being lost, or obliterated from his mind. With a knowledge of this language he may explore unknown regions, gather information, and make discoveries wherever its signs are current. This language enables him to understand the manners, customs, and wants prevailing in those regions. He may, indeed, without this knowledge, cross the frontiers of the known, and pass into the unknown territory; but he exposes himself to innumerable misunderstandings and errors. He asks for bread, and he receives a stone.

Medicine, *Physiology*, and *Geology* are the unexplored regions, the forms of government, laws, and institutions of which the philosopher is desirous of learning. Without a knowledge of the language of phenomena, and the art of interpreting it, there is nothing for him to discover but mere forms and external qualities.

Is it not obvious where the defects of physiology lie? Do we not perceive the internal conviction of our greatest physiologists in every experiment they make, in every word they utter? The mere knowledge of external forms and physical properties no longer satisfies them; they are deeply impressed with the importance, nay, the indispensable necessity, of a more profound, more intimate, more *chemical* insight into the composition and changes of organic bodies. But is such an insight possible without the knowledge of the chemical language?

If other and less highly-gifted physiologists maintain that chemistry is incapable of any useful application to their science, this is a most unjust reproach, since they understand neither the meaning nor the value of chemistry. They can no more read its language than they could a work written in Hebrew characters without having previously learned those characters.

It is not unworthy of remark, that many physicians profess to hold chemistry in contempt, exactly as they do with physiology; that medicine reproaches physiology, and with equal injustice, as she reproaches chemistry. The physician who has learned medicine, not as a science, but as an empirical art, acknowledges no principles, but only *rules* derived from experience. The object of his inquiries is only whether a remedy, in any given case, had a good or a bad effect. This is all the empiric cares about.

He never asks *why?* He never inquires into the *causes* of what he observes!

From what a different point of view should we contemplate the abnormal or diseased conditions of the human body, if we were first thoroughly acquainted with its normal conditions, if we had established the science of physiology upon a satisfactory basis!

How differently would the treatment of diseases be conducted if we had perfectly clear notions of the processes of digestion, assimilation, and excretion. Without just views of force, cause, and effect—without a clear insight into the very essence of natural phenomena—without a solid physiological and chemical education, is it to be wondered at that men, in other respects rational, should defend the most absurd notions; that the doctrines of Hahnemann should prevail in Germany and find disciples in all countries? Reason alone will not prevent whole nations from falling into the most abject superstitions, whilst even a child whose mind has been duly developed and instructed will repudiate the fear of ghosts and hobgoblins.

Can men who do not apprehend the nature of scientific investigation in a philosophical spirit, and who cannot interpret the language of phenomena,—can such men be expected to derive the least advantage from the discoveries of chemistry or physiology; and can they be deemed capable of making the most insignificant application to practical purposes of those discoveries? We often see such persons annoyed that truth should be so simple, and yet, in despite of all their efforts, they cannot succeed in deriving from it any practical advantages. From such persons emanate the most absurd, nay, impossible notions, and they have created for themselves, under the name of the *vis vitæ*, a miraculous thing by which they would explain all the phenomena they are unable to understand. With a totally incomprehensible, indefinable something, they would arrest inquiry and explain everything which is not comprehensible.

But this *vis vitæ* is itself but a subject of investigation, and in order to explore it, to comprehend its essence, to understand its operations and effects, the physician must pursue the same method which has been followed in natural philosophy and chemistry with such signal success.

There was certainly, at one time, no state of matter more obscure, more completely hidden from the corporeal and intellectual eye of man, than that which we denominate *electricity*. A thousand years elapsed from the birth of natural philosophy ere the human mind had obtained the slightest notion of the existence of this, the most stupendous power in nature, a power performing the most important part in all the alterations of inorganic matter, and all the processes of vegetable and animal life. The philosopher, undeterred by innumerable difficulties, has at length obtained, as the reward of his untiring researches, a most intimate knowledge of electricity, and has made it his handmaid. By a knowledge of electricity he is enabled to direct the course of the lightning, and to extract the noble metals from the poorest ores. By means of this force he was first enabled to ascertain the true nature of the constituents of the solid matters of our earth: with it, or with the allied influences, he sets ships in motion and multiplies costly objects of art!

When a power of nature, invisible and impalpable, is the subject of scientific inquiry, it is necessary, if we would comprehend its essence and properties, to study its manifestations and effects. For this purpose simple observation is insufficient, since error always lies on the surface and is gathered by the superficial inquirer, whilst truth must be sought in deeper regions.

If we apprehend a phenomenon or observed fact erroneously, or if we entertain an incorrect conception of its connections and relations, we are said to commit an error. Our only protection against this is to test the truth or falsehood of our notions by producing the phenomenon ourselves, under varied circumstances, and by ascertaining the conditions of its first appearance, varying these conditions, and closely observing the influence of these alterations. In this manner our first observation is corrected and rendered clear to our minds. Nothing must be left to the fancy or imagination.

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The true philosopher always seeks to explain and illustrate nature by means of facts, of phenomena; that is, by experiments, the devising and discovery of which is his task, and by which he causes the object of his investigation to speak, as it were, intelligibly to him. No single isolated phenomenon, taken by itself, can furnish us with its own explanation; but it is by carefully observing and arranging all such facts as are in connection with it, that insight into its nature is attained. For we must never forget that every phenomenon has its reason, every effect its *cause*.—BACON.

Such opinions as, that the creative energy of nature produces the most various kinds of plants, and even animals, out of decayed rocks or putrid vegetable matter, without seeds or sperm; that nature abhors a vacuum; that iron and phosphorus are formed, from other elements, in the living body of animals, and the like, are emanations of ignorance and indolence, and display men's incapacity to discover the true origin and causes of things. But a thousand unconnected observations have no more value, as a demonstrative proof, than a single one. If we do not succeed in discovering causes by our researches, we have no right to create them by the imagination. Thus, when we have learned that infusorial animalculæ are propagated by eggs, it only remains for us to inquire how the eggs are conveyed to where we find them. For the moment the imagination alone is taken for a guide, and is allowed to solve questions left undecided by researches, investigation ceases, truth remains unascertained, and there is not only this negative evil, but in error we create a MONSTER, envious, malignant, and obstinate, which, when at length truth endeavours to make its way, crosses its path, combats, and strives to annihilate it! Thus it was in the time of Galileo; and thus it is still, everywhere, in every science, where mere opinions are allowed to have the force of proofs.

If we confess the incompleteness of our knowledge, and simply admit our inability to answer the questions which arise as we contemplate the phenomena of nature, those questions remain as problems for futurity to solve, and excite the attention and exertions of thousands; zeal is kindled and kept alive, and in process of time their solution will certainly be accomplished. An explanation satisfies the mind; and if the explanation include error which is regarded as truth, this arrests the activity of the mind, as well as the progress of truth itself. The imagination, in thousands of cases, gives rise to thousands of errors, and nothing is more hurtful to the progress of natural science—nothing has more power in limiting and distorting our views of natural phenomena, than an old established error. It is infinitely difficult to refute a false doctrine, precisely because it rests on the conviction that that is true which is really false.

It is certainly not conformable to a rational philosophy of nature to attempt an explanation of the processes of formation, nutrition, and secretion in the animal body, before we have obtained a correct knowledge of alimentary substances, and the sources whence they originate, and before *albumen, caseine, blood, bile, cerebral substance, &c.*, had been subjected to a searching investigation. Before these substances have been successfully analysed, they are mere names, the letters composing which, at the utmost, we know, but whose signification is unknown. How can it be expected that any useful information should be derived from the mere terms, until the properties and relations of the substances themselves are known; until we have studied the metamorphoses they undergo when in contact with other bodies; until, in short, we have forced them to speak in answer to our questions?

The cause of the phenomena of life is a force, which does not act at sensible distances; its activity becomes manifest only when the aliments or the blood come into immediate contact with the organ destined for their reception or alteration. The chemical force manifests itself precisely in the same manner; indeed there are no causes in nature producing motion or change in bodies—no powers more closely allied to each other—than the chemical and vital forces. We know that wherever different substances are brought into contact with each other, chemical actions take place. To suppose that one of the most energetic powers of nature should take no part in the processes of the animal organism, although here all the conditions under which it commonly manifests its activity are united, would be against every established rule for the proper study of nature. But so far from there being any foundation for the opinion that chemical force is subordinate to the vital power, so as to become inoperative or imperceptible to us, the chemical effects of oxygen, in the process of respiration, (for example) are seen in full activity during every second of life. Moreover, *urea*, *allantoine*, the acid which is found in *ants* and *water-beetles*, namely *formic acid*, *oxalic acid*, the oils of *valerian root*, of the *Spiræa ulmaria*, of the *Gualtheria procumbens*, are products of the vital process, &c.; but is their production, we must ask, attributable to the vital force?

We are able to produce all these compounds by chemical processes, that is, by the chemical force. The chemist produces the crystalline substance found in the fluid of the allantois of the cow, from the excrements of snakes and birds: he makes urea from charred blood; sugar, formic acid, and oxalic acid from saw-dust; the volatile oil of *Spiræa ulmaria*, of *Gualtheria procumbens*, from willow-bark; the volatile oil of valerian from potatoes. These results are enough to justify us in entertaining the hope that we shall, ere long, succeed in producing *quinine* and *morphine*, and those combinations of elements of which *albumen* and *fibrine*, or muscular fibre, consist, with all their characteristic properties.

Let us, however, carefully distinguish those effects which belong to the chemical, from those which depend peculiarly upon the vital force, and we shall then be in the right channel for obtaining an insight into the latter. Chemical action will never be able to produce an eye, a hair, or a leaf. But we know, with absolute certainty, that the formation of hydrocyanic acid and of the oil of bitter almonds, in those seeds, of oil of mustard and of sinapine in mustard, and of sugar in germinating seeds;—that all these are the results of chemical decompositions. We see that the stomach of a calf, when dead, with the addition of some hydrochloric acid, acts upon flesh, and upon coagulated albumen, precisely in the same manner as the living stomach acts; that is, these substances become soluble, and are, in fact, digested. All this justifies us in inferring, that by the scientific investigation of nature, we shall arrive at a clear comprehension of the metamorphoses which alimentary substances undergo in the living organism, and of the action of remedies.

Without a profound study of chemistry and natural philosophy, physiology and medicine will obtain no light to guide them in the solution of their most important problems, that is, in the investigation of the laws of life, the vital processes, and the removal of abnormal states of the organism. Without a knowledge of chemical forces the nature and effects of the vital force cannot be fathomed ; the scientific physician can expect to derive assistance from chemistry only when he shall have qualified himself to put his questions to the chemist correctly.

Commerce and the arts have already derived immeasurable advantages from the progress of chemistry ; mineralogy has become a new science since regard has been had to the composition of minerals and the chemical relations of their constituents. If the composition and chemical nature of rocks and strata be not in like manner investigated (and this has hitherto been much neglected), it will be impossible to effect any considerable progress in geology. Chemistry, moreover, is the foundation of agriculture, and we cannot hope to give a scientific form and basis to this important art without a knowledge of the constituents of the soil, and of the substances which constitute the food of plants.

Without an acquaintance with chemistry, the statesman must remain a stranger to the true vital interests of the state, to the means of its organic development and improvement ; his attention cannot become sufficiently alive, nor his perception adequately acute, in regard to what is really useful or injurious to his country,—to society. The highest economic or material interests of a country, the increased and more profitable production of food for man and animals, as well as the preservation and restoration of health, are most closely linked with the advancement and diffusion of the natural sciences, especially of chemistry.

Without the knowledge of natural phenomena, and of the laws by which they are regulated, the human mind is incapable of forming an adequate conception of the greatness and unfathomable wisdom of the CREATOR; for all the images which the most inexhaustible fancy or the most cultivated intellect can form will appear, when compared with the reality, but as glittering, variegated, unsubstantial bubbles!

The great desideratum of the present age is practically manifested in the establishment of schools in which the natural sciences occupy the most prominent place in the course of instruction.

From these schools a more vigorous generation will come forth, powerful in understanding, qualified to appreciate and to accomplish all that is truly great, and to bring forth fruits of universal usefulness. Through them the resources, the wealth, and the strength of empires will be incalculably increased; and when, by the increase of knowledge, the weight which presses on human existence has been lightened, the difficulties of obtaining subsistence lessened, and man is no longer overwhelmed by the pressure of earthly cares and troubles, then, and not till then, will he be able to devote his intellect, purified and refined, to the study of higher subjects of investigation, and finally to the highest of all.

LETTER II.

THE history of man is the mirror of the development of his intellect. It shows us, in his acts, his faults and frailties, his virtues, his noble qualities, and his imperfections. The investigation of nature teaches us to recognise the omnipotence, the perfection, and the inscrutable wisdom of an infinitely higher Being, in his works and actions. So long as we are ignorant of these things, the perfect development of the human mind cannot be hoped for, or even conceived. Without this knowledge the immortal spirit of man cannot attain to a consciousness of its own dignity, or of the rank which it occupies in creation.

The religion of the Greeks and Romans—of the *heathen*—was, in its origin, founded upon an imperfect contemplation and false impression of natural phenomena. Those nations were intellectually blind to the immediate *causes* of the changes and fluctuations in things around them. They directed their prayers to the gross—the more obvious—powers of nature. Every superstition carries us back to heathenism. The exalted value, the sublimity of a right comprehension of nature, lies precisely in this, that it is the medium for a correct apprehension of Christian truth. And the divine origin of true Christian doctrine, indeed, is proved by the fact that we are indebted for it, and for a correct notion of a Being who is above all worlds, not to the imperfect way of empirical investigation, but to a higher enlightenment.

The space in which the systems composing the universe move, is illimitable. Were we to attempt to assign its limits, what could we imagine to be beyond? The number of worlds is infinitely great; it is inexpressible, indeed, by numbers. A ray of light traverses 180,000 miles in a second of time. A year comprises millions of seconds, yet there are fixed stars so immeasurably distant that their light has required billions of years to reach our eyes. We are acquainted with animals possessing teeth, and organs of motion and digestion, which are wholly invisible to the naked eye. Other animals exist, which, when measured, are found to be many thousands of times smaller, and which, nevertheless, possess the same apparatus. These creatures, in the same manner as the larger animals, take nourishment, and are propagated by means of ova which must consequently be, again, many hundreds of times smaller than their own bodies. It is only because our organs of vision are imperfect that we do not perceive creatures a million times smaller than these.

What variety and what infinite gradations do the constituents of our globe present to us in their properties and their conditions! There are bodies which are twenty times heavier than an equal volume of water, there are others which are ten thousand times lighter, the ultimate particles of which cannot be seen by the most powerful microscopes. Finally, we have in light,—that wonderful messenger which brings us daily intelligence of the continued existence of numberless worlds,—the expression of an extra-terrestrial essence which no longer obeys the laws of gravitation, and yet manifests itself to our senses by innumerable effects. Even the light of the sun—with the arrival of which, upon the earth, inanimate nature receives life and motion—we cleave asunder into rays, which, without any power of illumination, produce the most important alterations and decompositions in organic nature. We separate from light certain calorific rays, which exhibit among themselves a diversity as great as exists amongst colours. But nowhere do we observe either a beginning or an end. The human mind perceives in nature no limit either above or below itself, and in this infinity,—scarcely conceivable, since it is in both directions unfathomable by human power,—not one drop of water falls to the ground, not one particle of dust changes its place, without compulsion. Nowhere beyond the sphere of his own being does man perceive a conscious will; he sees everything around him bound in the chains of invariable, immutable, fixed laws. Within himself alone he recognises a *something* which may govern these effects, a *will* which has the power to rule over all natural laws, a *spirit* which, in its manifestations, is independent of these natural powers, and which, when it is in its conceivable perfection, is subject only to its own laws.

The mere empirical knowledge of nature forces upon us, irresistibly, the conviction that this *something* within us is not the limit beyond which there exists nothing similar or more perfect. The inferior gradations only of this *something* are accessible to our powers of perception. And this conviction, like every other truth in inductive natural investigation, affirms the existence of a higher, indeed of an infinitely exalted Being, to contemplate and to comprehend whom our senses are too feeble, and of whom, in his greatness and sublimity, we can only form some conception by the highest cultivation of every faculty of our minds.

The knowledge of nature furnishes us with the most effectual means of advancing our intellectual powers to this degree of perfection.

The history of philosophy informs us that the wisest men, the most profound thinkers of antiquity, and, indeed, of all ages, considered the insight into the essence of natural phenomena, the acquaintance with natural laws, as an indispensable means for cultivating the mind. The study of external nature—physical science—constituted a part of philosophy. Science renders the powers of nature the servants of man, whilst empiricism subjects man to their service. The empiric, placing himself on a level with an inferior or unconscious being, employs but a small portion of his power for the advantage of society. He permits effects to govern his will, whilst, by a true insight into their hidden connections, he might govern them.

The pertinence of these remarks will appear to you when I attempt, in a subsequent chapter, to explain one of the most remarkable laws which lies at the foundation of modern Chemistry.

If to the comparative anatomist, a small fragment of bone, a tooth, serves as a volume from which he can relate to us the history of a being belonging to a past world, describe its size and shape, point out to us the medium in which it breathed and lived, and demonstrate to us of what its nourishment consisted, whether animal or vegetable, and its organs of motion,—all this might be supposed to be the mere creation of a lawless imagination, if this small fragment of bone, this tooth, owed its form and constitution to mere chance. But the anatomist may safely assert all this as a reality, because every particle owes its form to definite laws, and because, when the form of a part is once known, it indicates the mode of construction of the whole.

It may not appear less wonderful to many that the chemist should be able, when he knows the proportion in which any single substance unites with another substance, to discover and to fix the exact proportion in which the former will unite with all other bodies whatever.

The discovery of these laws, to which all the processes comprising number and measure are subordinate, in organic as well as in inorganic nature, and which regulate and govern all chemical actions, is acknowledged to be the most important acquisition of the present century, and the most productive in its results.

LETTER III.

It is not easy to form an idea of the extent of chemical knowledge at the present day without casting a glance back to past ages. The history of science fills a page in the history of the human mind; and there is no department of science, the history of which is more interesting and instructive, in reference both to its origin and to its development, than chemistry. The received belief of the recent origin of that science is an error, originating in accidental circumstances. Chemistry is one of the very oldest of the sciences.

The same spirit which, towards the close of the last century, aroused in a highly civilised nation the insane endeavour to annihilate the monuments of its history and of its glory,—which raised altars to the Goddess of Reason, and introduced a new calendar;—that spirit gave rise also to a festival in which Madame Lavoisier, robed as a priestess, committed to the flames on an altar, while a solemn requiem was chanted, the phlogistic system of chemistry. At that period, the chemists of France associated themselves for the purpose of changing all the names and symbols which had been employed up to that time to designate chemical compounds, and to represent chemical processes. A new nomenclature was introduced, which, in the train of a new system, complete in itself, soon secured for itself a universal reception. This, then, was the origin of the apparently wide gulf separating modern from ancient chemistry. The history of every important discovery, of every separate observation, made up to the time of Lavoisier, in any part of Europe, was then blotted out; while new names and altered views tore asunder all connection with the past. To many, the knowledge we now possess appears to be only the inheritance of the French school of that day; and the history of true chemistry is supposed to reach no further back. But it is precisely here that the fallacy lies.

As in the history of nations there is no event which has not been preceded by other events or circumstances of which it is the consequence, so is it with the progress of all the natural sciences. In the same way as a phenomenon in any department of nature, living or dead, presupposes the conditions under which it has arisen, the progress of natural science is prepared by the previous acquisition of truths, which are either facts, or conclusions dependent upon and deduced from facts. A new system or a new theory always follows from observations, more or less comprehensive, which contradict the reigning doctrine; and in the time of Lavoisier, all the substances and all the phenomena which he studied, were already known. He discovered no new body—no new property—no natural phenomenon previously unknown; but all the facts established by him were the necessary consequences of the labours of those who had preceded him. His merit, his immortal glory consisted in this—that he infused into the body of the science a new spirit; but all the members of that body were already in existence, and rightly joined together.

Chemistry embraces the effects produced by natural forces of the most recondite kind which do not, like many physical forces or influences, such as light or gravity, make themselves known in forms of action daily arresting our attention. These forces do not act at sensible distances, but are only manifested in their results when different kinds of matter are brought into the closest contact. Ages were required to collect the world of phenomena of which chemistry consisted before Lavoisier appeared. It required innumerable observations before men were able to attempt the explanation of that most striking though familiar phenomenon, the burning of a candle—before they could seize the hidden clue, which led to the conclusion, that the rusting of iron in the air, the bleaching of vegetable colours, and the respiration of animals, were all dependent on the same cause as the combustion of inflammable substances.

In order to attain that knowledge of chemistry which we now possess, it was necessary that thousands of men, armed with all the science of their respective periods, and inspired with an unconquerable ardour, with a passion for knowledge, which, in its violence, bordered on madness, should devote life, fortune, and their whole faculties, to the task of exploring the earth in all directions. It was necessary that, with indefatigable perseverance and constancy, these men should bring into contact all known substances, organic and inorganic; it was necessary that these labours should be continued for fifteen centuries. There was, finally, a mighty, an irresistible charm, which urged men to devote themselves with an amount of patience and perseverance altogether unexampled in history—to labours which did not tend to supply any want peculiar to the time in which they lived. This mighty impulse was nothing else than the desire for earthly happiness.

By a wonderful and wise dispensation, there was implanted in the minds of the wisest and most experienced men the idea of the existence of a thing, hid in the bowels of the earth, by the discovery of which man might become possessed of those things which imply the gratification of the utmost desires of a refined sensuality—namely, gold, health, and long life. "Gold gives power; without health there is no enjoyment, and longevity here takes the place of immortality." (Göthe.)

These three primary essentials of earthly happiness were supposed to be united in the "philosopher's stone." For more than a thousand years, the grand, the ultimate object of all chemical labours was the search for that "virgin earth" coveted as the means of preparing the mysterious substance, which, in the hands of the philosopher or wise man, changes every base metal to gold, and which, according to a later creed, when used as a remedy in its highest perfection, cures all diseases, restores youth to the exhausted frame of age, and prolongs life indefinitely.

Rightly to appreciate and judge of the true nature of alchemy, we must remember, that till the sixteenth century the earth was regarded as the centre of the universe, and that the life and destiny of men were believed to stand in the closest relation to the motions of the heavenly bodies. The universe was a vast whole, an organism, the members of which stood in an uninterrupted relation of reciprocal influence. "From all the ends of heaven the creative forces radiate towards the earth, and determine earthly destinies." (Roger Bacon.) "When a man," says Paracelsus, "eats a bit of bread, does he not therein consume heaven and earth and all the heavenly bodies, inasmuch as heaven, by its fertilising rain, the earth by its soil, and the sun by his luminous and heat-giving rays, have all contributed to its production, and all are present in the one substance?" All that happened on earth stood written in starry characters in heaven. All that was thus written in heaven must of necessity happen on earth. Mars, Venus, or some other planet, ruled, from birth, the actions and the fortunes of individual men, while comets, lawless in their appearance, were the threatening symbols of want and woe to entire nations.

The knowledge and study of nature and of her powers included the science of magic, which, when combined with the healing art, was regarded as the true idea of secret wisdom. In the phenomena of organic life—in the vast operations of nature—in thunder and lightning, storm and hail, men recognised the agency of unseen spirits. Whatever insight a thinking man might have acquired by observation, was to him a possession, the source of which was not perceived by the multitude; it was a sign or mark of his intercourse with supernatural beings, and his knowledge became, in the eyes of the ignorant, the power by which he controlled the world of spirits. "Demons," says Cæsalpinus, "perceive by the inward mind, without requiring the aid of bodily senses, but without natural means they can exert no influence on men or animals. Those which are of an evil sort produce bewitchments and all kinds of mischance." "During four centuries, European jurisprudence sacrificed thousands of human victims to the belief of the existence of compacts between men and the evil one. The world was firmly convinced of the existence of such compacts, although these were of the most strange description, inasmuch as none of the parties to them derived any benefit from the agreement. For the unfortunates who had signed away their souls to the devil lived, for the most part, in the deepest poverty and misery, not even gaining earthly pleasures by the exchange, while their share of heavenly bliss gained by the enemy of mankind, was, to him, a worthless possession." (Carrière.)

When compared with this stage of development of the human intellect, alchemy, as far as regards a knowledge of natural truths, was in advance of other natural sciences. Chemistry, at that time, and up to the fifteenth century, stood on the same level,—it was no further back in its development than astronomy.

The idea of the philosopher's stone, considered as a means of transmuting the baser metals to gold, was spread abroad from Egypt, chiefly by the Arabians.

By the conquest of Egypt, they acquired possession of natural and scientific truths, perhaps originally attained by a jealous caste of priests, and which, being taught as mysteries in the temples, were accessible only to the initiated. Even Herodotus and Plato had early obtained instruction and knowledge in that remarkable country. Nine hundred years before the conquest of Egypt by the Arabs, the Alexandrine Academy already supplied a centre of scientific activity, and even down to the period of the burning of the vast library by the Arabs, Alexandria was the seat and the refuge of Grecian science. Among the Arabs, a people intellectually new and fresh, whose Mahometan fatalism opposed to the development of medicine, and whose maxims, derived from the Koran, expressly prohibiting research and reflection, were yet unable to check the progress or prevent the encouragement of the sciences, of medicine, astronomy, and mathematics; among these Arabs the views of the Alexandrian philosophers concerning the transmutation of metals found a prepared and fruitful soil ready for their reception.

At the time when Bagdad, Bassora, and Damascus were the centres of the commerce of the world, there was no nation more dexterous or more active in trade, or more eager for gain and gold, than the Arabs. Their tales and legends have preserved for us the favourite dreams and desires of that period, which were the motives of Arabian enterprise and activity. While the elves and nixes, the dwarfs and Undines, of the Germanic legends, appear as the bestowers of swords which no foe could withstand, or of unguents which healed every wound; of wine-cups ever full, or of tables ever-loaded with food; the genii of the Thousand and One Nights are always the guardians of immeasurable treasures, of gardens, whose trees are of gold and their fruits of precious gems. The wonderful lamp of the Arabian romancers, by means of which man could come into possession of these treasures, was obviously regarded as something as tangible and attainable as was the broomstick on which, many centuries later, the witches of Germany rode through the air to the Blocksberg, there to celebrate in wild and maddened dance the festival of the Walpurgisnacht. In Egypt, this mysterious object of desire took the form of the philosopher's stone.

From the Arabian universities, the endeavour after the discovery of the philosopher's stone, and with it, the acquisition of chemical knowledge, and the whole direction given to scientific research, was communicated to the north-west of Europe. On the model of the schools of Cordova, Seville, and Toledo, which had been frequented, since the tenth century, by the studious of all countries in their earnest pursuit of knowledge, there arose in Paris, Salamanca, Padua, and many other cities, universities, seats of the sciences; and in accordance with the cultivation of the period, the Christian clergy became the only possessors of the knowledge obtained by the researches of the Arabian philosophers, and the only persons capable of extending to the world the learning thus acquired. Many centuries later, the proverbially dark and mysterious explanations of the Egyptian priests,—their mystical, figurative style, mixed up with religious ideas,—continued to be peculiar to alchemy, the chemistry of the age.

The writings of Geber, the Pliny of the eighth century, give evidence of an extent of chemical knowledge, of facts experimentally established, which, when the period is considered, excites our wonder and admiration; and the theories of the great philosophers of the thirteenth century, Roger Bacon and Albert von Bollstadt (Albertus Magnus), Bishop of Ratisbon, may, for their fertility of ideas, and their comprehensive views of nature, be fitly compared only with those of the modern schools of natural science.

We classify bodies, at the present day, in groups, according to similarity or identity of properties; but the same thing was done in Geber's time. The metals possess in common certain fundamental properties; all of them have the metallic lustre; some metals are unchangeable in the fire, and these are the so-called noble or perfect metals. But the greater number, when exposed to the action of fire, lose their lustre and malleability; these were called the imperfect metals, or semi-metals.

At that period, lead-glance (or galena) and iron pyrites, having the metallic lustre, could not be separated or distinguished from metals, and were regarded as semi-metals. The former had the colour of lead, the latter approached in colour to gold. From both minerals, sulphur could be expelled; the lead-glance yielding, when thus treated, and without change in its lustre or colour, true, metallic, malleable and fusible lead. What was more natural than to conclude, that sulphur was an ingredient of the baser metals, the amount of sulphur determining their properties? Since then, lead-glance, by the expulsion of a certain quantity of sulphur, was converted into lead, was it not probable, that by the removal from lead of somewhat more sulphur, we might attain to a still higher purification or refinement of the metal, and thus convert it into silver?

The volatility of mercury was known. What was more natural than to conjecture that the loss of metallic properties, in the calcination of baser metals in the fire, or that the rusting of such metals in the air, depended on the escape of the volatile mercury?

Even at the present day, common experience leads us to suppose, in all coloured bodies, the presence of a colouring matter. The red of the ruby, the green of the emerald, and the blue of the sapphire, depend on causes analogous to those which determine the colour of dyed textures. Soft or malleable iron may be rendered hard by the addition of a small proportion of a foreign body; by a certain process, hard cast-iron may be rendered soft and malleable; copper, which is red, acquires a colour like that of gold, when heated with calamine (zinc ore), and may be rendered silver white by means of arsenic; gold itself, when heated with sal ammoniac, acquires a reddish tinge, while borax gives it a pale colour. Even our children are in the habit of changing iron into copper, as they imagine, when they immerse a knife in ink (containing sulphate of copper), in which experiment the iron, becoming coated with copper, disappears to their senses. Finally, the sand of certain rivers, when heated with certain fluxes, was known to yield gold; and red earth, ignited with oil, was found to be a source of iron.

What, then, was more natural to the inexperienced mind than to believe, that the properties common to all metals depended on substances, on certain ingredients; that by the removal or addition of certain matters, lead or copper might acquire the properties of silver or gold; that an imperfect tincture might give the colour, while a more perfect one would supply the other desired qualities?

No one can wonder that the old alchemists should have regarded as metals the compounds of metals with sulphur (sulphurets, such as lead-glance or pyrites); especially when he remembers that the chemists of our day for twenty-six years considered and described as metals an oxide of a metal (protoxide of uranium), and a compound of a metal with nitrogen (nituret of titanium).

"There are," says Geber, "as is proved by the facts above narrated," which in his point of view were certain and conclusive, "means of producing and transmuting metals. These means consist in three sorts of medicines. Those of the first order are the raw materials, or ores, as furnished by nature. Those of the second order are the substances of the first order, after being refined and purified by chemical processes. By the further ennobling and fixing of these is produced the medicine of the third order. This is the great Magisterium, the red tincture, the great elixir, the philosopher's stone."

In all metals, according to the creed of the alchemists, there is contained a principle, which gives to them the metallic character. This is the mercury of the adepts. To increase the proportion of this principle in the baser metals is to ennoble them. If we extract this metallic principle from any body or metal, if we increase its power by refining it, and thus produce the quintessence of all *metallicity* (to coin a word), we have the stone which, when made to act on base or unripe metals, matures and ennobles them. The mode of action of the philosopher's stone was considered by many as analogous to that of a ferment. "Does not yeast change the juice of plants or a solution of sugar, by a new arrangement of their particles, into the youth-giving and invigorating water of life? (*aqua vitæ,* alcohol). Does it not effect the expulsion of all impurities? Does not a ferment (sour dough) convert flour into nourishing bread?" —George Rippel, 15th century.

In its utmost perfection, as the *universale,* one part, according to Roger Bacon, sufficed to transmute a million parts—according to Raymond Lully, ten billions of parts—of a base metal into gold. According to Basil Valentine, the power of the philosopher's stone extends only to seventy parts; and John Price, the last alchemist and gold-maker of the eighteenth century, describes it as transmuting only from thirty to sixty parts of base metal.

For the preparation of the philosopher's stone the first requisite was the raw material, the Adamic earth, virgin earth, which is indeed to be found everywhere, but its discovery is dependent on certain conditions known to the initiated alone. "When we have once obtained this," says Isaacus Hollandus, "the preparation of the stone is only a labour fit for women, or child's play. From the *materies prima, cruda* or *remota,* the philosopher obtains first the mercury of the adepts, which differs from ordinary quicksilver, and is the quintessence, the first condition, of the creation or procreation of all metals. To this is added philosophical gold, and the mixture is left for a long time in an incubatory or brooding furnace, which must have the form of an egg. There is thus obtained a black substance, the raven's head, or *caput corvi,* which, after long exposure to heat, is converted into a white body. This is the white swan, *cygnus albus.* After this has been long and more fiercely heated, it becomes yellow, and finally bright red, and now the great work is consummated."

Other accounts of the process for preparing the philosopher's stone are rendered, by their being mixed up with mystical views, yet darker and more mysterious. The custom, too, prevalent in those ages, of regulating divisions of time by the hours of prayer, passed, during the tenth, eleventh, and twelfth centuries, into the laboratories of the alchemists; and it is easy to perceive how, by degrees, the success of the operation came to be regarded as essentially dependent on the efficacy of prayers, which prayers were at first used only to determine its duration. In the seventeenth century, the transformation of alchemistical ideas into religious notions had become so complete, that alchemistical expressions were frequently employed to designate religious ideas. In the writings of the mystics, (for example, in those of the enthusiastic Jacob Böhme, †1624,) the term "philosopher's stone" no longer signifies the substance which transmutes baser metals into gold, but "conversion;" the clay furnace is "the earthly body;" and the green lion is "the Lion of David."

Previous to the invention of printing, it was easy for an alchemist to keep secret his discoveries. He exchanged them only for the observations of other adepts. The chemical processes which they published are clearly and intelligibly described, in so far, at least, as they are not such as to lead to any practical result in reference to the chief object of their search; but they expressed their views, and described their labours, on the subject of the grand arcanum or Magisterium, in figurative language and in mysterious symbols. They propounded in an unintelligible language that which, in their own minds, was only the faint dawn of an idea.

That which chiefly excites our wonder is, that the existence of the philosopher's stone should have been regarded, for so many centuries, as a truth established beyond all doubt, while yet no one possessed it, and each adept only maintained that it was in the possession of another.

Who, indeed, could entertain a doubt, after Van Helmont had declared, in 1618, that on several occasions there had been sent to him, from an *unknown* hand, one-fourth of a grain of the precious material, with which he had converted into pure gold eight ounces of quicksilver? Did not Helvetius, the distinguished body physician to the Prince of Orange, and the bitter opponent of alchemy, himself relate, in his "*Vitulus aureus quem mundus adorat et orat,*" (1667,) that he had obtained the most convincing proofs of the existence of the philosopher's stone? For he, the sceptic, had received, from *a stranger*, a fragment of the size of half a rape seed, and therewith, in presence of his wife and son, had transmuted six drachms of lead into gold, which stood the tests applied to it by the Warden of the Mint at the Hague! Were not two pounds and a half of quicksilver converted into pure gold, of which a large medal was struck (Kopp. Geschichte der Chemie IV. 171), with the figure of the God of Day (Sol or gold) holding the caduceus of Mercury, to indicate the origin of the precious metal, and the legend DIVINA METAMORPHOSIS EXHIBITA PRAGÆ, XV. JAN., AN. MDCXLVIII, IN PRÆSENTIA SAC. CÆS. MAJ. FERDINANDI TERTII, etc.? Was not this done at Prague, in presence of the Emperor Ferdinand III. (1637-1657) by the Burgomaster, Count von Russ, with the aid of one grain of a red powder, which he had received from a certain Richthausen, and he again *from an unknown?* (According to J. F. Gmelin, this medal was still extant in 1797, in the treasury at Vienna.) The Landgrave of Hesse Darmstadt also, Ernst Ludwig, as we are told by the alchemists, received, *from an unknown hand*, a packet containing red and white tincture, with directions for their use. Ducats were coined of the gold which had been made from lead by this means, and from the silver thus obtained were coined the Hessian specie dollars (Species thaler) of 1717, on which is the legend SIC DEO PLACUIT IN TRIBULATIONIBUS. (Kopp. II. 172.)

It can hardly be doubted that the amateurs of alchemy in these cases experienced something similar to that which befel the distinguished and highly deserving Professor of Theology, Joh. Sal. Semler in Halle (†1791), who occupied himself at one time in experiments with a then renowned universal medicine, which was offered for sale under the name of atmospheric salt (*Luftsalz*) by a certain Baron von Hirsch. Semler thought he had discovered that gold grew, or was produced in this salt when kept warm and moist. He sent, in 1787, a portion of the salt with the gold grown in it to the Academy of Sciences, at Berlin. Klaproth, who examined it, found it to contain glauber salt (sulphate of soda) and sulphate of magnesia, enveloped in a magma or extract of urine, and gold leaf in considerable quantity. Semler also sent to Klaproth some of the salt in which no gold had yet grown, and a liquor which "contained the germ of gold, and which impregnated the atmospheric salt in a proper warm temperature." It appeared, however, that the salt was already mixed with gold. Semler firmly believed in the production of the gold. In 1788 he wrote, "Two glasses are bearing gold. Every five or six days I remove it; each time about twelve to fifteen grains. Two or three other glasses are in progress, and the gold blooms out below." A new portion which was sent to Klaproth in leaves of from four to nine square inches proved that the gold plant had unfortunately degenerated; for it now bore adulterated gold or pinchbeck. At last the matter was cleared up. Semler's servant, who had to take care of the hothouse, had introduced gold into the glasses, in order to give his master pleasure; but being on one occasion prevented from doing so himself, his wife undertook the business; but she was of opinion that pinchbeck leaf was much cheaper and would serve the purpose equally well.

In the fourteenth, fifteenth, and sixteenth centuries, however, men were not so familiar with the means of distinguishing genuine gold and silver from alloys of similar appearance as in the time of Semler. The impostures, which were practised on a great scale by the makers of gold, were not sufficient to weaken the popular belief in the reality of transmutation of metals. Henry IV., of England, in 1423, in four successive decrees, summoned all nobles, doctors, professors, and clergymen to devote themselves, according to their several abilities, to the study of the art, in order to procure the means of discharging the debts of the state. "The clergy," said the king, "should engage in the search for the philosopher's stone; for, since they could change bread and wine into the body and blood of Christ, they must also, by the help of God, succeed in transmuting the baser metals into gold." What success attended these decrees may be gathered from the fact, that the Scottish parliament subsequently ordered a strict watch to be kept in all the harbours of Scotland, and on the land frontier, in order to prevent the introduction of false money. It is said that the descendants of the gold-makers of that period still exercise their craft in Birmingham.

During the sixteenth century alchemists were found in the courts of all princes. The Emperor Rudolph II. and the Elector Palatine Frederick were known as patrons of alchemy. Men of all ranks studied transmutation, and strove to attain possession of the grand arcanum. Just as in the present day vast sums are expended by princes, private persons, and associations in mining enterprises for the discovery of metallic ores, of coal, or of strata of salt, so were vast sums squandered in the sixteenth and seventeenth centuries for the researches deemed necessary in order to discover the philosopher's stone. A multitude of adventurers appeared, who endeavoured, at the courts of the great and mighty, to pass for adepts, that is, possessors of the secret; but this was a dangerous game: for those who at one court, or at another, succeeded, by dexterously managed transmutations, in establishing their character as adepts, and carried off honours and riches as their reward, were sure finally to fail elsewhere; and their end commonly was, to be hung in a robe covered with gold leaf on a gallows adorned in a like manner. Those, again, whose imposture could not be proved, expiated the fatal honour of being believed to possess the philosopher's stone, under the hands of covetous princes, by imprisonment and tortures. Indeed, the cruel treatment which such adventurers experienced was regarded as the strongest proof of the truth of their art.—KOPP.

The great (Francis) Bacon, Benedict Spinosa, and Leibnitz believed in the philosopher's stone, and in the possibility of the transmutation of metals; and the decisions of Faculties of Jurisprudence prove how deep and how widely extended these ideas had at that period become. The Faculty of Law in Leipsic declared, in 1580, in their judgment against David Beuther, that he was proved to possess the knowledge of the philosopher's stone; and the same Faculty, in 1725, gave a decision in the affair of the Countess Anna Sophia von Erbach against her husband, Count Frederick Charles von Erbach. The lady had granted protection, in her castle of Frankenstein, to a fugitive, who was pursued and hunted like a wild beast; and he, who was an adept, had, to show his gratitude, converted the silver plate of the countess into gold. The count claimed the half of it, because the increase in its value had been obtained on his territory, and under coverture. But the Faculty decided against him, because the object claimed had been, before its conversion into gold, the property of the countess, and she could not lose her right of property in it by the transmutation.

In our day, men are only too much disposed to regard the views of the disciples and followers of the Arabian school, and of the late alchemists, on the subject of transmutation of metals, as a mere hallucination of the human mind, and, strangely enough, to lament it. But the idea of the variable and changeable corresponds to universal experience, and always precedes that of the unchangeable. The notion of bodies, chemically simple, was first firmly established in the science by the introduction of the Daltonian doctrine, which admits the existence of solid particles, not further divisible, or atoms. But the ideas connected with this view are so little in accordance with our experience of nature, that no chemist of the present day holds the metals, absolutely, for simple, undecomposable bodies, for true elements. Only a few years since, Berzelius was firmly convinced of the compound nature of nitrogen, chlorine, bromine, and iodine; and we allow our so-called simple substances to pass for such, not because we know that they are in reality undecomposable, but because they are as yet undecomposed; that is, because we cannot yet demonstrate their decomposability, so as to satisfy the requirements of science. But we all hold it possible that this may be done to-morrow. In the year 1807, the alkalies, alkaline earths, and earths proper, were regarded as simple bodies, till Davy demonstrated that they were compounds of metals with oxygen.

In the last twenty-five years of the preceding century, many of the most distinguished philosophers believed in the transmutation of water into earth. Indeed, this belief was so widely prevalent, that Lavoisier, the greatest chemist of his day, thought it advisable, in a series of beautiful experiments, to submit to investigation the grounds on which it rested, and to point out their fallacy. Such notions as that of the production of lime during the incubation of eggs, and of iron and metallic oxides in the animal and vegetable vital processes, have found, even in the present century, acute and enthusiastic defenders.

It is the prevailing ignorance of chemistry, and especially of its history, which is the source of the very ludicrous and excessive estimation of ourselves, with which many look back on the age of alchemy; as if it were possible or even conceivable that for more than a thousand years the most learned and acute men, such as Francis Bacon, Spinosa, and Leibnitz, could have regarded as true and well-founded an opinion void of all foundation. On the contrary, must we not suppose, as a matter beyond a doubt, that the idea of the transmutability of metals stood in the most perfect harmony with all the observations and all the knowledge of that age, and in contradiction to none of these?

In the first stage of the development of science, the alchemists could not possibly have any other notions of the nature of metals than those which they actually held. No others were admissible or even possible; and their views were consequently, by natural law, inevitable. Without these ideas, chemistry would not now stand in its present perfection; and in order to call that science into existence, and in the course of 1500 or 2000 years to bring it to the point which it has now reached, it would have been necessary to create the science anew. We hear it said that the idea of the philosopher's stone was an error; but all our views have been developed from errors, and that which to-day we regard as truth in chemistry, may, perhaps, before to-morrow, be recognised as a fallacy.

Every theory which urges men to labour and research, which excites acuteness and sustains perseverance, is a gain to science; for it is labour and research which lead to discoveries. The three laws of Kepler, which are regarded as the foundation of modern astronomy, were not derived from just views of the nature of that force which retains the planets in their revolutions and in their orbits, but are simply deductions obtained by the art of experimenting; that is to say, by labour and research.

The most lively imagination, the most acute intellect, is not capable of devising a thought which could have acted more powerfully and constantly on the minds and faculties of men, than that very idea of the philosopher's stone. It was that same force which urged thousands of adventurers, with and after Columbus, to venture fortune and life on the discovery of a new world, and which, in our day, drives hundreds of thousands to cross the mountains of Western America, and thus to spread cultivation and civilisation over that hitherto neglected part of the globe.

In order to know that the philosopher's stone did not really exist, it was indispensable that every substance accessible to study and observation should be observed and examined, in accordance with the scientific resources of the time. But it is precisely in this that we perceive the almost miraculous influence of the idea. The strength of the opinion could not be broken, till science had reached a certain stage of development. During centuries, as we have seen, whenever doubts arose, and the labourers became languid in their efforts, a *mysterious unknown* was sure to appear at the right moment, who convinced some prominent and trustworthy man of the reality of the great Magisterium.

A person ignorant of science, who takes the trouble to read a simple page of a Manual of Chemistry, must feel the utmost astonishment at the mass of individual facts there recorded. Almost every word, in such a book, expresses an observation or a phenomenon. These observations did not present themselves to the observer; they were laboriously sought for and obtained. What would be the present position of science without sulphuric acid, which was discovered by the alchemist more than a thousand years ago, without muriatic acid, nitric acid, ammonia, the fixed alkalies, the numberless compounds of metals, alcohol, ether, phosphorus, or prussian blue? It is impossible to form a just conception of the difficulties which the alchemists had to overcome in their researches; for they were of necessity the inventors of the apparatus or instruments, and of the processes which served for the production of their preparations, and they were compelled to make with their own hands everything which they employed in their experiments.

Alchemy was never at any time anything different from chemistry. It is utterly unjust to confound it, as is generally done, with the gold-making of the sixteenth and seventeenth centuries. Among the alchemists there was always to be found a nucleus of genuine philosophers, who often deceived themselves in their theoretical views; whereas the gold-makers properly so-called, knowingly deceived both themselves and others. Alchemy was the pure science, gold-making included all those processes in which chemistry was technically applied. The achievements of such alchemists as Glauber, Böttger, and Kunkel, in this direction, may be boldly compared to the greatest discoveries of our century.

Many of the fundamental or leading ideas of the present time appear, to him who knows not what science has already achieved, as extravagant as the notions of the alchemists. Not, indeed, the transmutation of metals, which seemed so probable to the ancients, but far stranger things are held by us to be attainable. We have become so accustomed to wonders that nothing any longer excites our wonder. We fix the solar rays on paper, and send our thoughts literally with the velocity of lightning to the greatest distances. We can, as it were, melt copper in cold water, and cast it into statues. We can freeze water into ice, or mercury into a solid malleable mass, in white-hot crucibles; and we consider it quite practicable to illuminate most brightly entire cities with lamps devoid of flame or fire, and to which the air has no access. We produce, artificially, ultramarine, one of the most precious minerals; and we believe, that to-morrow or next day some one may discover a method of producing, from a piece of charcoal a splendid diamond; from a bit of alum, sapphires or rubies; or from coal-tar the beautiful colouring principle of madder, or the valuable remedies known as quinine and morphine. All these things are either as precious or more useful than gold. Every one is occupied in the attempt to discover them, and yet this is the occupation of no individual inquirer. All are occupied with these things, inasmuch as they study the laws of the changes and transformations to which matter is subject; and yet no one individual is specially engaged in these researches, inasmuch as no one, for example, devotes his life and energies to the solution of the problem of making diamonds or quinine. Did such a man exist, furnished with the necessary knowledge, and with the courage and perseverance of the old gold-makers, he would have a good prospect of being enabled to solve such problems. The latest discoveries on the constitution and production of the organic bases permit us to believe all this, without giving to any one the right to ridicule us as makers of gold.

Science has demonstrated that man, the being who performs all these wonders, is formed of condensed air (or solidified and liquefied gases); that he lives on condensed as well as uncondensed air, and clothes himself in condensed air; that he prepares his food by means of condensed air, and, by means of the same agent, moves the heaviest weights with the velocity of the wind. But the strangest part of the matter is, that thousands of these tabernacles formed of condensed air, and going on two legs, occasionally, and on account of the production and supply of those forms of condensed air which they require for food and clothing, or on account of their honour and power, destroy each other in pitched battles by means of condensed air: and further, that many believe the peculiar powers of the bodiless, conscious, thinking, and sensitive being, housed in this tabernacle, to be the result, simply, of its internal structure and the arrangement of its particles or atoms; while chemistry supplies the clearest proof, that, as far as concerns this the ultimate and most minute composition and structure, which is beyond the reach of our senses, man is, to all appearance, identical with the ox, or with the animal lowest in the scale of creation.

But to return to alchemy. In judging of it, we are but too apt to forget that a science represents a spiritual organism, in which, as in man, self-consciousness first appears at a certain stage of its development. We now perceive that all the special objects pursued by the alchemists have contributed to the attainment of a higher end than that of which they were conscious. The path which has led to this result was obviously the best. To build a palace, we require many stones which must be quarried, and many trees which must be felled and hewed; but the plan comes from above, and is known to the architect alone.

The philosopher's stone, for which the ancients sought with a dim and ill-defined impulse, was, in its perfection, nothing else than the science of chemistry. Is that not the philosopher's stone which promises to increase the fertility of our fields and to ensure the prosperity of additional millions of mankind? Does not chemistry promise that instead of seven grains we shall be enabled to raise eight or more on the same soil? Is that science not the philosopher's stone which changes the ingredients of the crust of the earth into useful products, to be further transformed, by commerce, into gold? Is that knowledge not the philosopher's stone which promises to disclose to us the laws of life, and which must finally yield to us the means of curing diseases and of prolonging life?

Every new discovery opens up wider and richer fields to our researches; and in the laws of nature we are still ever seeking the "virgin earth" of the alchemists, a search which can never have an end.

Ignorance of the history of science is the cause why we frequently look back with a kind of contempt also to the second period of chemistry, namely, the phlogistic period, and regard it as insignificant. Our self-esteem deems it inconceivable that the experiments of John Rey, on the increase of weight in metals during the operation called calcination, remained unregarded; and that, while these experiments existed, the idea of phlogiston could be developed and obtain a footing. But all the efforts of that age were directed to the arrangement of that which was ascertained, and which waited only for arrangement. Rey's observations had no influence whatever on that period, because they were not yet brought into connection with the process of combustion generally ; and this being the case, were there not many bodies, which, in the same circumstances, became lighter, or disappeared entirely to the senses? The object of all the labours of Becker and Stahl and their followers was the discovery of those phenomena which belonged to the same class and were produced by the same cause.

That the calcination of metals and the production of sulphuric acid from sulphur, and, on the other hand, the recovery of metals from their calces and of sulphur from sulphuric acid, were analogous processes closely related to one another ; (before Stahl it was not even known that in calx or rust of iron, iron still remained, or that sulphur still existed in sulphuric acid, and that both iron and sulphur could be recovered from these bodies, rust of iron and sulphuric acid,) this great and incomparable discovery determined the progress of chemistry to our time. In that discovery lies a truth, which is still acknowledged as such, and is quite independent of the knowledge of the relative weights. Before men could begin to weigh, they needed to know what was to be weighed ; before applying weight, measure, or numbers, it was necessary to know the existence of a relation between two objects, the nature and amount of which relation was to be determined. To have discovered and established such relations, in connection with the most important of all processes, the process of *combustion*, this is the immortal glory of Stahl.

We value facts because of their permanence and immutability, and because they supply the soil for ideas ; but a fact acquires its true and full value only through the idea which is developed from it. Many facts were not in possession of Stahl, but the idea is his property. Cavendish and Watt both discovered the composition of water. Cavendish established the facts; Watt the idea. Cavendish says, "From inflammable air and dephlogisticated air water is produced." Watt says, "Water consists or is composed of inflammable air and dephlogisticated air." Between these forms of expression there is a wide distinction.

The attaching too high a value to the *mere* facts is often a sign of a want of ideas. It is not fertility, but poverty of ideas which clothes itself with a mass of coverings of all sorts, or wears old, tattered, threadbare, and ill-fitting garments.

There are ideas so great and vast, that even when entirely perforated, as it were, in all directions, they leave enough of matter to occupy the powers of thought of mankind for a century. Such a great vast idea was that of phlogiston.

Phlogiston was originally an idea, and the question as to its material existence was void of all significance, so long as the idea was fruitful in the classification of known facts, and prepared the way for new generalisations. When men took up, in their explanation (of combustion), the notion of weight, they discovered the degree in which the process depended on a peculiar ingredient of the atmosphere; but the phenomenon itself was not thereby better or more completely explained than before. The proportion in which air, or any other body, became heavier in combustion, was not known to Stahl; and the question, in what relation the process of decomposition, in virtue of which light and heat are developed, stands to the process of combination, or to the gain or loss of weight?—this is a problem unsolved to the present day. The difference is, that we push aside, and in a manner neglect, the phenomenon which Stahl regarded as the chief one.

That which is developed in accordance with natural laws cannot proceed faster than it actually does. It was only after men had become acquainted with palpable objects, that the chemistry of invisible bodies could acquire a form. The modern idea of a chemical compound has proceeded from pneumatic chemistry; but in Stahl's time, the notion of the chemical character of a gas or of the air was not yet developed. It was on the loss of volume, or on the disappearance of a gas, that men first saw and recognised chemical attraction. Hales, in 1727, saw air (or gas) produced from a number of bodies by the action of heat. Everything that possessed the gaseous form and elasticity was to him simply *air*; and he was not struck with the remarkable differences between carbonic acid gas, inflammable gases, and atmospheric air. He explained the diminution of volume in a gas by contact with water or in combustion, not by solution or combination, but by a loss of the expansive power. The masterly researches of Black laid the foundation of the anti-phlogistic chemistry. The fundamental experiment of Lavoisier, the calcination and reviving of red oxide of mercury and the absorption and reappearance of an ingredient of the air on these processes, is only an imitation of Black's experiments on lime and the alkalies. When Black showed that quicklime exposed to the air becomes mild (or carbonated) and increases in weight—when he proved that this increase of weight depended on the absorption of a gas (carbonic acid) from the atmosphere, which gas could be again expelled by heat,—when he demonstrated that the increase of weight in the lime was equal to the weight of the absorbed gas;—when Black did all this, then began the epoch of quantitative research, of the use of the balance. Phlogiston lost its significance; the idea was replaced by a firmly linked chain of facts.

Many chemists, even at the present day, find it impossible to do without certain collective names, analogous to the word phlogiston, for processes which they regard as belonging to the same class, or determined by the same cause. But instead of choosing for this purpose words which designate things, as was the custom till the end of the seventeenth [*qu.* eighteenth? W. G.] century, (phlogiston means, for example, fire, or light, and heat), they employ, since the time of Berthollet, terms which designate what are called "forces." For example, nothing can be more opposed to the rules of philosophic research than is the invention and the use of the word *catalysis* or *catalytic force.* We all know that no essential truth is expressed in that word; but the majority of mankind, from the want of just conceptions, cannot do without it; and the necessity for classification and connection of observed facts will, even in the case of the minority, ensure its acceptance and use, until the facts to which it refers shall have been duly arranged and classified.

It has been said that every science must pass through three periods of development. The first is that of presentiment, or of faith; the second is that of sophistry; and the third is that of sober research. Alchemy is regarded as the religious period of the science afterwards called Chemistry. But this opinion is decidedly erroneous, as far as concerns all the inductive sciences. To investigate the essence of a natural phenomenon, three conditions are necessary. We must first study and know the phenomenon itself, from all sides; we must then determine in what relation it stands to other natural phenomena; and, lastly, when we have ascertained all these relations, we have to solve the problem of measuring these relations, and the laws of mutual dependence; that is, of expressing them in numbers.* The science of

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* The phenomenon of the effervescence of limestone and of potashes with acids has been known from the earliest times; but it was in the seventeenth century that the observation was first made,

chemistry embraces all those phenomena of the material world which are determined by a certain number of natural forces or causes (such as chemical attraction, heat, light, cohesion, gravitation, &c.); and its historical development exhibits three periods, corresponding to the three conditions above specified, as being essential to the full knowledge of any individual phenomenon.

In the first period of chemistry, all the powers of men's minds were devoted to acquiring a knowledge of the properties of bodies; it was necessary to discover, observe, and ascertain their peculiarities. This is the alchemistical period. The second period embraces the determination of the mutual relations or connexions of these properties; and this is the period of phlogistic chemistry. In the third period, in which we now are, we ascertain by weight and measure, and express in numbers, the degree in which the properties of bodies are mutually dependent. The inductive sciences begin with the substance itself; then come just ideas; and lastly, mathematics are called in, and, with the aid of numbers, completes the work.

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that this effervescence proceeded from the escape of a kind of air, different from common air; that this air occurs in certain mineral waters; that it is formed in fermentation, and produced also in the combustion of coal; that animals are suffocated, and flame extinguished, in it. Centuries passed before the *phenomenon* of effervescence was known in every point of view, and then it was discovered that the mildness and causticity of lime and of alkalies *depended* on the absence or presence of carbonic acid; that the hardening of mortar was caused by an absorption of carbonic acid from the atmosphere; that the development of carbonic acid in the fermentation of wine and beer *depended* on the decomposition of sugar, &c. At last, carbonic acid was resolved into its elements, its composition was determined, and the proportions by weight were ascertained, in which it combines with lime and other basic oxides of metals; while we also became acquainted with the amount or proportion in which its gaseous state depends on heat and pressure, with its specific and latent heat, and with its properties in the liquid and solid forms.

The political, as well as the scientific history of nations, shows us, in like manner, three periods. In the first, the qualities and faculties of men are developed, in all their varieties and contrasts. Weakness submits to strength: wisdom and the gift of invention are honoured as godlike qualities; the general conditions of the social compact are laid down in the form of commandments. All these commandments begin with the words "Thou shalt;" men have duties, but no rights. In the next period are developed the relations of mutual dependence among these qualities. The contest between opposite qualities leads to the adoption of laws; from the consciousness of that which is right, is developed the sense of the possession of rights, political and social. By the union of similar rights, political powers arise. The struggle of opposite powers (such as democracy, oligarchy, and monarchy,) leads to revolutions; and revolution is the name given to those processes by which a disturbed equilibrium is restored. In the third or last period, that amount, degree, or proportion of mutual dependence among all qualities, rights, and powers, which secures to the individual, without injury to others, the fullest and freest development of all his faculties and qualities, is fixed; and thenceforth revolutions are at an end.

LETTER IV.

NUMBERLESS germs of intellectual life fill the universe, but it is only in a few rare minds that these germs find a soil in which they can be developed. In these chosen minds the idea, whose origin is unknown, shows its vitality in creative acts; in them, the mysterious laws of nature assume a form, efficient, active, and recognisable by all.

It is not to the warlike deeds of mighty princes and renowned generals, but to the never-dying names of such men as Columbus, Copernicus, Kepler, Galileo, and Newton, that history refers the past progress in natural science, and the intellectual advancement of the present time. The doctrines of the church, invading every branch of knowledge, and the prevalence of a false philosophy, had arrested the free expansion of the human intellect for a thousand years. A system of teaching, like that of the Celestial Empire, which even now excites in the learned men of China a peculiar sense of pleasure in the reading of pages of meaningless names, had annihilated, in the full blossom of the scholastic philosophy, all desire after the investigation of truth. Like a tree which, when checked in its growth by external impediments, is crippled into the strangest shapes, so did the noblest mental powers languish and become deformed in the unyielding mould of hair-splitting dialectics. Men of acknowledged reputation and learning wrote books and treatises on storms, or on showers of blood, in which they discussed every thing, save only the explanation of the phenomena.

Whether Adam, while yet without sin, was already acquainted with the "Liber Sententiarum" of Petrus Lombardus?*—what was the age and dress of the angel who brought the message to the holy Virgin Mary?—whether there had existed in Paradise, before the fall, the necessary excretions of the human body?—whether the angels spoke Greek or Hebrew?—how many thousand angels could stand on a needle's point without crowding? To these, and similar questions and researches, which in our times would be regarded as valid evidence of insanity or

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* Died 1164, as Bishop of Paris.

folly, were the most distinguished intellectual powers devoted. Renowned philosophers corresponded at great length concerning the gift possessed by the Kings of France and England, of healing scrofula by the mere touch. They disputed as to whether this miraculous gift adhered to the throne or to the family. It was reckoned among the hidden forces, the existence of which was sufficiently demonstrated by experience.

In order to find the right path, the human mind requires a guide acquainted with it; but a secret and mysterious power held the light imprisoned; and in this intellectual darkness, no guiding star was seen. The treasure which the early times had acquired in the form of true knowledge of nature was not duly appreciated nor regarded, and thus lost its power to enrich and fertilise. Questions of physical science were decided according to the rules of the "*Ars Disputandi.*"

In renouncing the aid of experiment and observation, which alone create science, man thus banished true science. From the want of materials for the exercise of thought, men lost the habit and dexterity given by practice, of putting just questions as to the causes of things or phenomena, of observing them, and of discovering their connexions by experiment. Such a state of matters enables us to comprehend the supremacy of astrology, of the Cabala, of chiromancy, and the belief in lycanthropy and sorcery. It explains how, centuries later, diseases could be regarded as direct judgments of heaven, or as works of the devil; and how prayers, amulets, holy water, and relics, were considered the most efficient remedies. The story of the golden tooth, at the end of the sixteenth century, proves how entirely men, even in the more cultivated classes of society, had lost the power of successfully investigating the simplest phenomenon. (See Appendix.)

When Columbus had to defend his views concerning the shape of the earth, and the possibility of circumnavigating it, in Salamanca, the first seat of learning of the age, before an assembly consisting of the most learned professors of astronomy, geography, and mathematics of the Spanish Kingdom, along with the wisest and most respected dignitaries of the church, he appeared to the majority as a dreamer worthy of ridicule, or as an adventurer deserving of contempt.

And yet never had a learned disputation a greater influence on the development of human intellect than that one in the collegiate church of St. Stephen, at Salamanca. It was the dawn of a new day,—the forerunner of the great victory of truth over the blind faith of the age. In these remarkable discussions mathematical demonstrations lost their validity, when they *seemed* to contradict passages of Holy Scripture, or *the interpretations of those passages by the fathers of the church*. "How could the earth be spherical, when it is said in the Psalms, that the heavens were stretched out as a garment?" "How was it possible to regard the earth as otherwise than flat, when the sacred writer compares the heavens to a tabernacle or tent, spread out over the earth?" "Had not Lactantius thus pronounced against the existence of antipodes—'Is there any one so mad as to believe that there are men whose feet stand opposite to ours, and who are able to walk with their legs upwards and their heads hanging down: that there is a part of the world where all things are topsy-turvy—where the trees grow with their branches downward, and where hail, snow, and rain fall upwards?'" "Did not St. Augustine say, that the doctrine of the antipodes was altogether irreconcileable with the historical foundation of the Christian faith? for that whoever said that there were inhabited countries on the opposite side of the earth, asserted that there existed in those countries men who were not derived from Adam; since it was impossible for his progeny to pass the intervening ocean. Such an opinion must destroy our belief in the Bible, which expressly declares that all men spring from one pair of parents." "What presumption was it in a common man to believe that so great a discovery was reserved for him, after so many profound philosophers and geographers had made the shape of the earth the object of their researches, and so many good seamen had sailed over its surface for two thousand years?"—Thus spoke the opponents of the great man.

Two years later, Columbus returned from the West Indies! The earth was small and spherical, and there were inhabited countries at the other side of it!

But not only the earth, the heavens also contradicted the doctrines of the great luminaries of the golden age of churchly wisdom. For, in consequence of the discoveries of Copernicus, the earth had ceased to be the centre of the universe. It was not only small, narrow and spherical—it was a mere point in endless space—a small planet revolving round the sun.

As an indescribable feeling of terror attacks him who is surprised by an earthquake, when he feels that undulating like a rolling sea, which custom and reflection have taught him to regard as the most fixed and immoveable; so did fear and doubt convulse the civilised world in consequence of the discoveries of science. The earth was no longer the centre of the system of the universe; the vault of heaven had lost its columns—the throne of God its place. There was no longer anything above nor anything below. That which faith regarded as firmly rooted was shattered; what had been held as truth now appeared to be error. Numerous prophecies, in the first half of the sixteenth century, connected the discovery of the new with the destruction of the old world. They testify to the intense excitement of that age.

After Columbus had deprived the ocean of its terrors, and Copernicus had taught, "that confidence in the power of knowledge, which bursts the bands of external authority, and only yields belief to the evidence of reason,"* the courage necessary for the investigation of unknown regions of intellect awoke also in other minds.

The agent was already in existence which was to propagate the mighty shock through all the regions of science. As the blood which is the condition of all bodily action receives its motion from the impulse of the heart, so did Guttenberg's invention of printing send warmth and vigorous life to all parts of the intellectual organism now assuming its new form.†

In consequence of the foundation of numerous universities (as of Oxford in 1300, Prague in 1347, Vienna in 1384, Heidelberg in 1385, Cologne in 1388, Erfurt in 1392, Cracow in 1401, Würzburg in 1406, Leipsic in 1409,) and of the diffusion of Greek learning in the west of Europe, after the conquest of Constantinople by the Turks, in 1453, the attention of men's minds was turned, in the fourteenth and fifteenth centuries, to the intellectual treasures bequeathed by the old Greeks and Romans. Classical antiquity, like the sun, diffused a life-awakening light. When the learned began to learn from these unapproachable models, and to form themselves upon them, their mental vision was sharpened. The study of the classics, leading to a critical testing of all traditionary learning, broke the chains of the wisdom of the schools. Men recognised in nature the inexhaustible

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* Carrière, in his distinguished work, "The Philosophical Consideration of the period of the Reformation, in its relations to the present," p. 125; published in German by Cotta, Tübingen, 1841.

† In the same year in which Columbus was born, Guttenberg invented printing by moveable types.

fountain of a purer knowledge; and nature appeared as a newly-discovered Atlantis, formerly submerged, intellectually, in a sea of ignorance.

The mightiest champion arose for the purity of religious belief. Luther, in his Table-talk, most aptly describes the love of nature and its study, which arose with the Reformation.* "We are now in the morning dawn of the future life, for we again begin to acquire a knowledge of God's creatures which we lost through Adam's fall. Now, we look at the creature earnestly, more than as it were in the light of the Papacy. But Erasmus asks not after this, and cares little how the fruit is formed, shaped, and made in the mother's womb. But we, by God's grace, begin to perceive His wonders and His works, even in the little flowers, when we think how all-powerful and good God is. We do see in his creatures the power of his word—how mighty that is."

Nature put forth unusual powers to secure victory to reason in the contest then beginning between the intellect of European nations, awakened to consciousness of itself, against ecclesiastical and civil tyranny—against a mighty superstition which appeared impregnable. A number of the greatest men followed in uninterrupted succession, till the great work was done and its results secured. A hundred years after Copernicus, Kepler was born, and Newton saw the light in the same year in which Galileo died.

The church of the middle ages had set up, in its theological philosophy, a universal science, and had fortified it with the whole authority of a religious belief. An error in science was a vice; to deviate from the established doctrine was heresy; it was synonymous with a rejection of the Revelation from Heaven. Tortures and the stake awaited the man who thought freely, or otherwise than the church.

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* Carrière, p. 116.

An ignorant and jealous priesthood saw in the diffusion of the sciences the most dangerous means by which their power might be undermined; for with the study of natural laws, natural phenomena lost the supernatural character by means of which the minds of men were governed. A century after Luther, Galileo, at the command of the church, was compelled, in the dungeons of the Inquisition, to recant his doctrine of the earth's motion; and the words he murmured, "*E pur si muove,*" when he rose from his knees, clad in a bare shirt, to this day retain the idea of the irresistible force of established facts. No one can even now read his celebrated letter to Madama Christina, Granduchessa Madre, without emotion, and yet it did not convince his opponents. (See Appendix.) But all these obstacles had, in the long run, as little success in arresting the expansion and progress of science as at a later period attended a thirty years' war in the attempt to control religious opinion. Error is transient; truth alone is eternal. Error is only the shadow cast by truth, when its rays are arrested on their path by human ignorance and intellectual opacity.

In that eventful age chemistry also underwent a transformation. Being conjoined with medicine, chemistry acquired a new object, and entered on a new direction.

Alchemy had forged the weapons wherewithal chemistry was to conquer, in medicine, a new region, and put an end to the thousand years' reign of the Galenic system.

The great and salutary change which medicine underwent, its liberation from the fetters of authoritative belief, was the natural result of the recognition of the unattainableness and inaccuracy of all the previously received doctrines on the true nature of material objects. The new light was a trophy gained by the alchemists; and by its aid the doctrines of the Greek philosophers, concerning the causes of natural phenomena, acquired a new form.

In all ages the reflecting man endeavours to account to himself for the origin of things, and to penetrate the causes of their peculiarities. The most natural method was unquestionably that of the mathematicians, who, without external aid, study and ascertain the laws and properties of mathematical figures. This was in truth the method chosen by the Greek philosophers in order to obtain a knowledge of natural phenomena. They regarded the various and manifold properties of bodies as things apart, or *per se*, and sought, with the aid of the understanding, to combine their observations, and to discover such properties as are common to all bodies.

"The origin and properties of all things," says Aristotle, "presuppose three fundamental causes. The first is matter devoid of properties (ὕλη); the second is the cause, or causes, which give to matter its properties, and which may be collected in the conception of bodily form (εἶδος); the third is a cause, or causes, (forces in the sense contained in the words, force or power of a remedy, nutritive force or power,) which change bodies by depriving them of their properties (στέρησις, robbery). That which precedes the change of properties in matter is the cause, or efficient cause (τὸ ποίων, that which works); and that which follows the efficient cause is the effect (τὸ τέλος, the end or object)."

This conception of the properties of material bodies as of things, like colours, with which the painter gives to white canvas the properties of a picture, or like clothes, which are put on and off, and thus determine the aspect of the man, is the foundation stone of alchemy, and of the first scientific system of medicine.

It would be difficult for the most acute intellect, without using other means than simple perception by the senses, to discover more than four properties which belong to all tangible material objects.

To the senses of sight, taste, and smell, material bodies offer infinite varieties; there are coloured and colourless substances; there are those which possess taste and smell; and there are those which are inodorous and tasteless.

But all bodies are either moist or dry, either warm or cold. Everything tangible possesses two of these properties; it is either solid or fluid, and has a certain temperature.

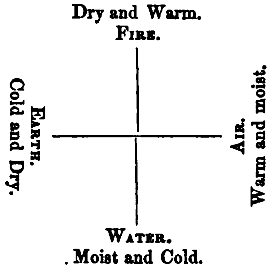
"These properties," says Aristotle, "are obviously opposed to each other; for cold can be destroyed by heat, dryness by moisture. By the conjunction of two properties, not opposed to each other, for example, of dryness and cold, we see solid bodies produced; while, by the action of heat and moisture, they become liquid or gaseous. Hence the mutual relations of these properties are clear; not only the form, whether solid or fluid, and the cold or warm state of bodies, but also the relative density and lightness, are determined by these fundamental properties. Cold is the cause of density, for by its action the material particles are brought into closer contact; porosity or lightness is in like manner caused by heat. But all the other secondary properties of matter stand also in a definite relation to the four primary or fundamental properties; for the colour, smell, taste, lustre, hardness, &c., of bodies suffer changes by the addition or subtraction of moisture, heat, dryness, or cold."

"It is plain," continues Aristotle, "that all those properties of tangible bodies which are perceived by the senses are *dependent* on these four primary properties; for with a change in the latter all the others undergo a change likewise. It is evident that the secondary properties are determined by the primary; and that there are four *elementary* properties of matter.'' The justice of these abstractions, as far as they embrace those properties of matter which can be ascertained by simple perception, cannot be disputed. The difference between our present views and those of the ancients consists in this, that we regard the solid, liquid, and gaseous states as well as the temperature of matter, as being determined by two, instead of four, opposite causes. At this hour we believe that all the external physical properties of bodies are dependent on the force of cohesion and the force of heat, according to fixed relations between these opposing causes.

'' Among four things,'' says Aristotle, '' there may be six combinations, two and two (pairings) ; but the pairing of two directly opposed properties, such as cold and heat, dryness and moisture, causes both to disappear. They destroy or neutralise each other, and can no longer be recognised by the senses. Consequently only four combinations are left, which correspond to the four bodies of which the earth consists. The earth proper, as the representative of solidity, is dry and cold; water (which represents liquidity) is moist and cold; air (representing the gaseous state) is moist and hot; fire hot and dry. From this pairing of properties arise the four material elements ; from these four elements are formed all other bodies. They are contained in all ; and the varieties and differences in the properties of other bodies depend entirely on the proportion in which the four elements are combined. Whatever element predominates gives its character to the body.''

As may be seen from the following diagram, the elementary bodies, taken two and two, have a primary or fundamental property common to both members of each contiguous pair.

It is hence evident that when, by means of old, the elementary property of heat is withdrawn from the air (gaseous body), the air is changed into water (liquid body); and, in like manner, by the aid of



heat, water may be changed into air, and by the aid of dryness, water converted into earth.

Fire, according to Aristotle, embraces the conception of brightness and sensation; water and air that of transparency; earth that of darkness. Colours arise from the mixture of fire and earth. The transparency of rock crystal proceeds from water. (The transparency of the diamond is still called, from this view of Aristotle, its water.) But the chief constituent of the eye also is water, as air is the foundation of the sense of hearing; air and water of that of smell; while earth is the condition of the sense of touch. Taste is produced by moisture; the more closely the particles causing taste adhere to the tongue the bitterer; the more easily they are separated from it, the salter a body appears. But when these are heated, and in turn heat the particles of the mouth, there is produced the acrid taste; and the sour taste is observed when the particles of the body are in fermentation and effervescence.

We perceive that, in all these cases, the physical peculiarity of those things which affect the sense, being ascertained with judgment and accuracy, is regarded by Aristotle as the determining cause. That which he observed in the effect was, according to him, the cause of that effect, and the explanation of natural phenomena was nothing more than the description of their peculiarities.

These doctrines of the Greek philosophers were made by Galen the foundation of the first theoretical system of medicine.

According to Galen, all the parts of the organised body are produced by the mixture, in different proportions, of the four elementary qualities of matter. In the blood they are equally mixed; in mucus, water; in the yellow bile, fire; and in black bile, earth, predominates. The four temperaments depend on the preponderance of these four cardinal juices.

Health is a state of equilibrium determined by the just conformation of similar parts, that is, of organs, and by the just mixture of the elements. In disease these relations are disturbed; disease is a state of conformation or mixture opposed to the natural state.

In consequence of the misproportion of the elementary qualities, the juices are found to be too hot, too cold, too moist, or too dry. When their motions are arrested, and transpiration is impeded, there occurs a corruption of the juices, and the various forms of fever are produced. The unnatural heat of fever is a result of this putrefaction. By the putrefaction of the mucous or slimy fluids, of yellow or of black bile, quotidian, tertian, quartan, and other fevers are excited.

According to Galen, the efficacy of remedies depends on the fundamental qualities inherent in each; they are hot or cold, moist or dry. A remedy, according to the amount of the fundamental quality of heat, may produce a hardly perceptible or a distinct warmth; it may excite heat more or less intense; and each quality has four similar degrees in its action. Substances of a burning taste belong to the hot, those of a cooling taste to the cold remedies.

The removal of disease on the restoration of health depends, according to Galen, on the supply of the deficient quality by communication, or in a removal of that which is in excess, by means of a remedy which tends to abstract it.

In this consistent system, disease and the action of remedies were reduced to a very limited number of causes. Diseases, like remedies, admitted of classification on a certain number of divisions; and when he had ascertained the place in the arrangement to which a disease was to be referred, the physician found, in the corresponding division, the appropriate means of restoring health. He knew the origin of the disease; and he knew why the remedy cured it.

In place of the empirical art and the method of experience, which had led Hippocrates of Cos to his innumerable observations and his admirable system of dietetics, there now appeared the theory, which combined, arranged, and explained these observations. The treatment of diseases followed by the great physician of Cos could be learned only by imitation; the new system was infinitely better adapted for teaching, and the acquisition of medical knowledge was rendered much easier.

The Greek philosophers, as well as Galen, had no conception of the peculiar properties, which are brought to light when different bodies are brought into mutual contact.

It is easy to perceive, that the fundamental idea of the Galenic system was quite identical with that which guided the alchemists,—the idea, namely, of the possibility of transmuting the elementary bodies by the addition or subtraction of elementary qualities. Lustre, colour, fixity in the fire, and volatility could be removed and supplied, according to the belief of those days; they could also be exalted and diminished. Gold was the most perfect metal, to which no properties could be added, because it possessed all.

Among metals, it represented the healthy human frame. "Bring to me," cries Geber, "the six lepers (silver, mercury, copper, iron, lead, and tin), that I may heal them." Brass was diseased gold, quicksilver was diseased silver; they could be transmuted into gold, that is, healed by the medicine of the third or highest order.

The origin of gold was regarded as analogous to the generation of animals, or to the origin and growth of plants. Raymond Lully compares the production of the philosopher's stone with digestion, with the origin of the blood, and the secretion of organic juices.

In the course of their labours, the alchemists had noticed certain peculiarities in the properties of bodies, which had remained unknown to the Greek philosophers, or disregarded by them; and by degrees three new elements, the existence of which was doubted by no one, were added to the four elements of Aristotle. To the four fundamental causes of the physical properties of matter, were now added three fundamental causes of the most general chemical properties; namely, mercury, sulphur, and salt.

In the spirit of the earlier philosophy, which ascribed all causes of action not perceptible by the senses to invisible spirits, and all sensible properties to tangible and material causes, common sulphur and quicksilver were regarded at first as actual constituents of the metals; certain properties were believed to be dependent on their presence, exactly as, at a more recent period, the causticity of lime and the alkalies was ascribed to the *causticum* or caustic principle, the peculiar smell of certain bodies to the *Spiritus rector*, and the acidity of the acids to a primitive or original acid.

The nature of the language of ordinary life, which avoids all abstract ideas, explains why men, in the infancy of research, ascribed a certain character or certain properties of bodies to material causes. Even Lavoisier could not shake off the idea of a primitive acid. He regarded oxygen as the generator of this primitive acid; and long after his time, many still see in hydrogen the cause which determines acidity.

In the ideas of the alchemists, actual sulphur and mercury were gradually supplanted by an ideal sulphur and an ideal mercury; things, which combined in themselves a certain number of properties. These ideal bodies, at a later period, took the form of elementary qualities.

Many bodies possessed the property of being volatile without alteration in their other properties, when exposed to fire. They were sublimable, like *arsenic*, or capable of being distilled, like *mercury*. Another class of bodies was also volatile, but underwent a change in the fire, such as *sulphur*. A third class, although changed in the fire, was not volatile, but fixed, like the *salts* found in ashes. Sulphur, mercury (arsenic), and salt became at last, as has been stated, abstract conceptions, simple elements, in the sense of the four elements of Aristotle. As we speak of the form and shape of a thought, without understanding by these figurative terms a bodily shape, so did men in those days express abstract notions by terms indicating bodily or material things, without understanding thereby anything more than properties. The names given to these ideal things became collective names for certain properties, and we often use similar terms at the present day, with this difference, that, to designate their immaterial nature, we add the word 'force,' as in the term "catalytic force."

Basil Valentine says of spirit of wine: "When a rectified aqua vitæ is kindled, its mercury and sulphur separate, the sulphur burns quite vividly, for it is pure fire, and the delicate mercury flies into the air, and returns to its original chaos."

Spirits of wine was regarded as "sulphureous vegetable mercury," which only meant that it possessed inflammability and volatility.

When, in the simple notions of inflammability (sulphur), fixity (salt), and volatility (mercury), men came to include the special qualities of inflammable, fixed, and volatile bodies, according as these were observed (oily, fat, earthy mercury; oily, fat, earthy, easily or difficultly inflammable sulphur; earthy, fusible, vitreous salt; inflammable, fat, oily, mercurial earth, &c.); then the significance of the original notion was lost. Becoming too wide and extended, it no longer included observed facts; and when Boyle searched after the sulphur, mercury, and salt of the alchemists, these elements no longer existed. The idea was worn out. At a much later period, the notion of a suffocating property, was designated by *sulphureous*, the combustion of a fixed body by *calcination*; that is, these things possessed one property in common with burning sulphur or with limestone (calx).

Hence it is no longer possible to give a definition of the terms "acid" and "salt," which shall include all those bodies which are called acids or salts. We have acids which are tasteless, and which do not redden vegetable blues, nor neutralise the alkalies; there are acids of which oxygen is an ingredient, and hydrogen is absent, others which contain hydrogen and no oxygen. The notion of a salt at last became so perverted, that chemists have gone so far as to exclude from the class of true salts, by their definition, common sea salt, the salt of all salts, to which all others owe their very name.

We can readily see, how easily a simple, defined notion becomes undefined, by the addition of other notions. In the place of the worn-out idea, we obtain, when we begin to distinguish, a number of new and more defined and separate ideas. It is even possible that the original idea, all but its name, may be lost; and the time may come, when we shall no longer find an acid or a salt, just as we could not find the sulphur and mercury of the alchemists, when these ideas were no longer necessary to science. Formerly, their existence appeared obvious to every man; and they were only sought for when mankind had no further occasion for them.

The chemical elements of the early philosophers could not, it is obvious, be obtained in a separate form, because they were merely terms, denoting qualities alone. No one thought of obtaining them; they were regarded as constituents of all bodies.

No distinction was made between organic and inorganic or mineral substances; their differences were ascribed to the different proportions of the elements. Vinegar was classified with the mineral acids. Spirits of wine was ranked beside chloride of tin (spirit of Libavius); and chloride of antimony (butter of antimony) next to the butter of the cow.

In the time of Geber, the chemical process was considered analógous to the organic process; in the thirteenth century the idea arose that the vital process might be analogous to the chemical. In the earliest period it was believed that metals were developed from a seed or germ; at a later period the opinion prevailed, that the chemical process generated the seed. The ancients held the processes of fermentation and putrefaction to be the cause of the generation of plants and animals; while, on the contrary, some physiologists and pathologists of the present day regard the development and generation of animals and plants as the cause of fermentation and putrefaction.

The views and conceptions entertained of Nature can only be rendered comprehensible to the mind by means of images or notions, derived from natural science, and clothed in the language of Nature. Now if we reflect that during the thirteenth, fourteenth, and fifteenth centuries, all knowledge of Nature and of her powers was concentrated in alchemy, magic, and astrology, it is easy to see how, by degrees, alchemistical forms of expression for terrestrial processes passed into the language of ordinary life. The phenomena of organic life, life itself, death, and resurrection, were rendered more intelligible by means of the ideas derived from alchemy; they could only be represented scientifically by the language of science, and alchemy was science at that period.

"We poor mortals," says Basil Valentine, "are, for our sins here, by means of that death which we have well deserved, pickled in the earthly, that is, the kingdom of earth, till, in process of time, we become putrid and rot, and then are once more awakened, clarified, and sublimed, by virtue of the heavenly fire and heat, even to the celestial sublimation and elevation; for all our dross, sins, and impurities are sundered from us." (Kopp. ii. 236.) Luther, in his *Canonica*, praises alchemy, "by reason of the glorious and fair resemblances which it has to the raising of the dead; for even as fire from each kind of thing doth extract that which is best, and doth sunder it from the bad, and thus doth carry the spirit itself upwards, so that it shall have the upper place, whereas matter, like unto a dead body, doth remain below lying on the earth, so also will God, at the last day, by his judgment, as with fire, sunder the godless and unrighteous from the righteous and godly. The righteous will ascend to heaven, but the unrighteous will abide below in hell." (Kopp. ii. 238.)

In the thirteenth century arose for the first time the idea that the philosopher's stone possessed the powers of healing disease and of restoring youth. This idea was developed from the opinion that the vital process was nothing else than a chemical process. With the philosopher's stone it was possible to heal metals of their maladies, to render them healthy, to convert them into gold; and the idea that it must have a like effect on the human body naturally suggested itself. Arnold of Villanova, Raymond Lully, and Isaac Hollandus, outdo each other in their praises of its healing virtues. Hollandus, in his *Opus Saturni*, says: "A portion of it, the size of a grain of wheat, should be laid in wine, and then given to the patient. The action of the wine will penetrate to the heart, and spread itself through all the juices. The patient will sweat, and thereby become, not more weary, but ever stronger and more cheerful. This dose should be repeated every ninth day, when the patient shall think he is no longer a man, but a spirit. He shall feel as if he were nine days in Paradise, and living on its fruits." Solomon Trismosin maintains that when an old man he renewed his youth by means of a grain of the philosopher's stone. His yellow wrinkled skin became smooth and white; his cheeks rosy; his grey hair black; his back, bowed with age, became erect. He restored, as he asserts, perfect youthfulness to ladies ninety years of age!

When the idea that the philosopher's stone was a universal medicine had been once developed, men were led, in the most natural way, to the use of chemical preparations in medicine; and with this began a new era in that science.

If, indeed, the stone possessed in an equal degree the properties of ennobling the baser metals, and of healing disease, then the diseased human body was a far more convenient means of recognising the *materia prima*, and of testing its gradual refinement in the course of the processes by which it was elaborated into the perfect Magisterium. For the number of diseases which the preparation, at a given stage of its elaboration, could heal, was an infallible test of its progress towards perfection. The more diseases it cured, the nearer must it be, in its properties, to the philosopher's stone. The true and perfect stone must heal all diseases.

The Pharmacopœia of the Galenical school contained no chemical preparations, and consisted exclusively of organic substances: musk, rhubarb, castoreum, camphor, tamarinds, ginger, zedoary root, and the like, were the chief remedies. Pharmacy then consisted in the art of bringing these matters into the forms of syrups and electuaries; herbs, barks, and roots, were administered in the form of decoctions or of powders.

On the authority of Galen, all metallic preparations were, up to that time, banished from the Pharmacopœia. He regarded mercurial preparations simply as poisons. Avicenna, it is true, had ascribed to gold and silver powers of purifying the blood; but these metals, as a general rule, were used only in the form of leaf, to cover pills; and so late as at the end of the fifteenth century, the external use of mercurial ointments, prepared with fat, encountered the fiercest opposition.

When we consider that the views of Galen, in regard to the cause of disease and the action of remedies, were regarded, during thirteen centuries, as impregnable truths, and had acquired the entire infallibility of the articles of a religious creed, we can understand what kind of impression must have been produced on the physicians of the sixteenth century by the discovery of the truly wonderful effects of the preparations of mercury, antimony, and other metals. A whole region of new discoveries seemed to be opened up by the ideas of the alchemists, and by the use of chemical preparations in medicine.

There was discovered, in the blood, a property belonging to alkalies; in the gastric juice, a property belonging to acids. A contrast or opposition was noticed between these fluids, corresponding exactly to the contrasts of the Galenic qualities.

When acids were brought into contact with alkalies, new bodies were formed, neither acid nor alkaline, but possessed of properties entirely changed. The so-called mild alkalies exhibited the property of effervescence with acids, and the true nature of all fermentations, which were regarded as dependent on effervescence, appeared to be thereby explained. Heat was observed to be developed in liquids by the mixture of acids with alkalies, without the observer's perceiving proper combustion to take place. This appeared to account for the heat developed in the respiratory process.

How was it possible any longer to allow any validity to the theory of Galen concerning the vital phenomena and the action of remedies, after it had been proved that all his views in regard to the metals and their preparations were entirely fallacious; or when it had been discovered that the peculiarities of the organised body, and the effects of remedies, depended on fundamental causes, which Galen had not taken into account in his explanations, because he was not acquainted with them. Not only those fundamental causes, which determine the physical properties, but also the chemical properties of bodies, must now and henceforth sit in council and be taken into account, in explaining organic processes. The vital phenomena and the action of medicines now, as it appeared, depended, not alone on the relative proportions of moisture and dryness, of heat and cold, but, in addition to these, on the proportions of salt, mercury, sulphur, alkali, and acid. In consequence of such new and altered ideas, the art of healing assumed a new form.

If the normal *chemical* character of the juices was the condition which determined the healthy state, the abnormal character of these juices was of course the proximate cause of disease; and disease could be removed by the predominating chemical quality of remedies, and health thus restored.

In selecting remedies, then, especial attention must be paid to the chemical constitution and character of the bile, of the saliva, of the sweat, and of the urine, &c. This was a step forward of incalculable importance. The valuable discovery was soon made, that the chemical state of the urine stood in a definite relation of dependence to certain diseases; and as, in the period of science now under review, all effects were taken for the causes, the deposits formed in the urine, or the tartar, were regarded as the causes of many diseases.

In the spirit and mind of Paracelsus the new ideas of the times were concentrated, and assumed a definite shape; and when, a few years after, Luther, at Wittenberg, had burned the papal bulls, Paracelsus, at Basle, following the example of the great reformer, committed to the flames the works of Galen and Avicenna, their reign came to an end.

"Men," so said Paracelsus, "have abandoned nature, and given themselves up to vain dreams;" therefore he pointed to the open book of Nature, "which God's finger hath written. No dim study-lamp, but the sun itself, shall supply us with the true light. The eyes, which have pleasure in looking, they are the right professors. Nature is without guile, righteous and entire. From book-craft and from the working of men's fancy do grow confusion and sham fights." "Follow me!"—thus he opens his *Paragranum*—"Follow me! I follow you not, O Avicenna, Rhases, Galen, Mesur! Follow me! I follow not you, O ye of Paris, ye of Montpellier, ye of Swabia, ye of Misnia, ye of Cologne, ye of Vienna, and ye who dwell on the Danube and by the Rhine, ye isles of the sea, thou Italy, thou Dalmatia, thou Athens, thou Greek, thou Arabian, thou Israelite!

Follow me! I follow not you! Mine is the monarchy!"

In Paracelsus are reflected all the ideas, all the faults, all the errors of his time. In him a gigantic force strives against the impediment of outward fetters. He has the instinct, but not the full consciousness of the right path. He seeks it in vain in the wilderness that surrounds him; hence his contradictions and inconsistencies; hence his internal struggles. But his word gives to the century its direction. "The true use of chemistry," he says, "is not to make gold, but to prepare medicines."

By Paracelsus chemistry was taken out of the hands of the gold-makers, and brought into the service of the far more learned and cultivated physicians; and as he and his followers prepared their own medicines, chemical knowledge and an acquaintance with chemical operations were thenceforth regarded as among the most essential qualifications of the physician.

In the sixteenth and seventeenth centuries, the explanation of natural phenomena continued to revolve round the idea of the existence of hidden qualities, until extended experience led to the important truth, that matter and its properties are practically not separable. We cannot any longer even conceive of them as separate.

Long after Paracelsus, it was believed that the chemical operation was to the medicine what the stomach (or digestion) is to the food from which the blood is formed. By a thrice-repeated sublimation of corrosive sublimate with metallic mercury, calomel was obtained; a sublimation nine times repeated produced the *Panacea mercurialis*.

The spiritualising fundamental causes of Plato, which, according to him, determined the vital actions, are combined by the followers of Paracelsus, into the *archæus*, which is placed in the stomach, and being furnished with all the passions of the man, governs digestion, the phenomena of motion, and the moods of the mind.

When we represent distinctly to ourselves the utter contempt with which modern medicine looks down on the views of Paracelsus and his followers, regarding their views, like the ideas of the alchemists concerning transmutation of metals, as a hallucination, and compassionating them accordingly, and when we compare with these views the present theories of the causes of diseases, and of the method of cure; the philosopher, with all his pride in the achievements of the intellect in the regions of truth, is humbled by the daily occurrence of contradictions, which we should hold impossible, if they did not actually exist. For even now the system of Galen and Paracelsus rules, as it did formerly, over the minds of most physicians; and many views remain unchanged, except in the forms of expression. The *archæus* of the sixteenth century was transformed, in the eighteenth and the beginning of the nineteenth centuries, into the vital force of the philosophers; and it lives on to the present day in the guise of the all-determining nervous force or influence. No one can deceive himself as to the true position of theoretical medicine who remembers that in our age, in which the true principles of investigation appear to shed abroad their light, clear and brilliant, like the sun, a doctrine was able to develope itself in medical science, which to our posterity will appear incredible.

Who can maintain that the majority of well-informed and cultivated men of our time stand on a higher level in regard to knowledge of Nature and her powers than the iatro-chemists of the sixteenth century, when he knows that hundreds of physicians, trained in our universities, regard as true, principles which defy alike all experience and sound common sense; that there are men who believe that the effects of medicines are due to certain forces or qualities, which, by means of grinding and shaking can be set in motion and increased in force, and thus communicated to inert bodies; who believe that a law of nature, to which no exception is known, is false for medicines, since they admit that their efficacy may be increased with their dilution and with the diminution of active matter? Truly, one is tempted to adopt the opinion that, among the sciences which have for their object a knowledge of nature and of her forces, medicine, as an inductive science, occupies the lowest place. Just as the farmer expects wonders from a new plough, a new sowing-machine, a new manure, or a new mode of cultivation,—although these things, without just principles, can only waste his substance, and render him poor sooner than he would have been without them,—so the physician looks for the progress of his science in the improvement of its technical part. In a new medicine, a new mode of treatment, or in the restoration of an imaginary composition of the blood or of the urine, he seeks, not to remove the stone which impedes the progress of his vehicle, but, like the carter, to urge the horse with his heavy load when he can no longer advance over the obstacle, by the use of the whip. And when Nature helps herself, he wishes us to believe that the whip is a power and has been the means of restoring health. All these things are useful, perhaps necessary; but they are not used in order to clear away the difficulty for all who are to follow, but serve only to enable him to skip over it in the easiest manner in the individual case. That which most readily presents itself to the imagination is used as a bridge; but if the philosopher gets safely across, he allows it to fall to ruins behind him, instead of giving it a secure foundation. If he fails, the imperfection of science is blamed for his failure. The art of experimenting makes tools or instruments; but it has never happened that a mass of observations has become a science by virtue of the tools or instruments.

There are building materials in abundance, so as almost to cover the ground on which the edifice should stand; but the master builders are quarrelling, and their minds are not made up as to the place. One would have the structure of wood; another thinks it ought to be of stone and wood; a third, that it should consist only of stone and iron. Two of these materials should at all events be employed; but all three, if properly combined, would yield an excellent building, were it not for the labourers, who will have it made of straw, and built in the air. It is because of this that in the course of two thousand years even the foundation has not been finished.

LETTER V.

THE first point to which I would claim your attention in my intended exposition of the principles of Chemistry, is that tendency of bodies to combine with each other, usually termed CHEMICAL AFFINITY.

In order to obtain a clear and vivid comprehension of the almost miraculous order and regularity in which bodies enter into combination with each other, we must bear in mind the meaning which the chemist attaches to the terms *combination* and *decomposition*. The rusting of iron, the bleaching of coloured stuffs when exposed to the air, the extraction of metals from their ores, the preparation of innumerable objects of industry and commerce, and of medicines,—in short, all new forms or phenomena which present themselves to our senses when bodies of different properties are brought into contact;—all, with a very few exceptions, depend upon combination or decomposition. The ultimate causes of these new forms and phenomena are chemical forces, and these differ from all other forces, inasmuch as we perceive their existence only by their manifestations when bodies come into immediate contact with each other. As long as they remain at any measurable distances these forces have no action whatever. The domain of Chemistry is confined to this class of phenomena. Gravity, the electrical and magnetic forces, and heat, exercise an influence upon chemical processes; but as powers which act at a distance, which produce motion, or change of place, in bodies, in short, as causes of natural phenomena, the determination of their nature and their laws, in the narrower sense, belongs to *physics*.

Iron rusts when exposed to the air. Sulphur and mercury combine, forming cinnabar. It is the CHEMICAL FORCE which is active between a constituent of the atmosphere (oxygen) and the particles of the iron,—between the particles of the sulphur and the particles of the mercury,—and by which the change of their properties is effected. This chemical force is the cause of the formation of a new body with altered properties, that is, of *a chemical compound*.

We obtain, again, the mercury from cinnabar by heating it with iron; and we obtain metallic iron from iron-rust by heating the latter to redness with charcoal. We *decompose* the cinnabar by iron, and iron-rust by charcoal. The cause is, invariably, chemical force; the result invariably rests upon the formation of a compound. The iron which separates the mercury combines with sulphur. We had sulphuret of mercury, we now obtain sulphuret of iron. The charcoal which reproduces metallic iron from iron-rust enters into combination with that constituent of the atmosphere (oxygen) which the iron had imbibed, and which has caused the rust.

The infinitely numerous chemical decompositions of compound bodies, the separation of one of their constituents, invariably depends upon this, that a newly added substance enters into combination with the remaining constituents. It is quite evident that these substances, under the given conditions, would not experience any change of properties, unless the cause which we designate "chemical force" were active between their particles. This chemical force, or influence, has been styled *affinity*, in total defiance of the vernacular acceptation of the word. It is said that two substances have an affinity when in contact with each other, they exhibit the faculty of combining together. This term (affinity) is decidedly fallacious, if it be intended to convey the meaning that such substances are related to each other.

Were we to place the sixty-two known elements promiscuously upon a table, a child would be able to divide them, by their external appearance, into two great classes:—one class, the individuals of which possess a metallic aspect; another class, deficient in this appearance. The first comprehends the *metals*, the latter class of bodies the *metalloids*.

These principal classes, according to the similarity of several individuals in other properties, may again be divided into smaller groups, in which those most closely resembling each other shall stand together. In the very same manner compound bodies manifest similarities or dissimilarities in their properties; and if we arrange them into families, and thus bring those together which originate from the same elements, it will be found that the members of one and the same family have but very little, and frequently not even the slightest, tendency to combine with each other. They are related, or, in the usual sense of the word, possess affinity, in their properties; but they have no attraction, no affinity, in the chemical sense of that term, for each other: whilst the members of two different families, which have most dissimilar properties, have always the most powerful attraction for each other.

Thus, the compounds formed by two members of the same family possess all the more apparent qualities and defects of that family in an undiminished, and frequently in an increased, degree; But if two substances of quite opposite families enter into alliance, a new body is invariable formed, in which we cannot recognise the original parents.

Thus, iron and mercury (two metals) stand infinitely more closely related to each other, than iron and sulphur, or mercury and sulphur (a metal and a metalloid); in a compound of the two former we immediately recognise its origin; but who, looking at cinnabar, would guess that this substance contains the silver-white fluid metal and the yellow inflammable sulphur? Hence result, in the compounds themselves, various degrees of *affinity*, by which term we always designate the unequal tendency or faculty of their atoms to combine with each other; and it is upon these various degrees of attraction that all decompositions depend.

It has been already stated that it is indispensably necessary to the manifestation of chemical affinity that the atoms of substances should be in immediate contact with each other, or at immeasurably small distances. Now every one knows the effect which heat exercises upon bodies. However firmly you may drive an iron nail into the wall, it will gradually become loose, and at last fall out. In summer the iron is more heated than during winter, it therefore expands in summer, and with great power forces wood and stone asunder, whilst in winter the iron contracts in a greater degree than stone or wood. Expansion by heat implies that the atoms of which a substance is composed separate to a certain distance from each other. Now since a certain contiguity of atoms is a necessary condition for the action of chemical affinity, it is obvious, that by the mere effect of heat a number of chemical combinations must be resolved into their constituents; and this, indeed, always, in cases where the influence of heat causes the distance between the ultimate particles to extend beyond the sphere of their chemical attraction. This necessarily causes a separation. When the heat decreases, the atoms again approach each other, and at a certain point of proximity combination again ensues. We may imagine that at a temperature immeasurably high to us, substances can exist in one and the same space, without combining, although they may possess the very strongest affinity for each other, and that, precisely because this high temperature neutralises their affinity,—opposes an insurmountable resistance to its operation. So, undoubtedly, the constituents of the earth, when they possessed an exceedingly high temperature, were arranged in quite a different manner from that in which we find them at present. Nay, it is not impossible that they should have floated through each other, as in a chaos, and that this chaos formed itself into our present minerals and rocks only when this temperature was greatly lowered.

Let us suppose all the elements composing the earth, by the influence of a great heat, to be brought into the same state in which oxygen and hydrogen gas exist at the common temperature of the atmosphere; the earth would be an enormous ball of nothing but gases, which everywhere would uniformly mix without entering into combination; just as is the case with oxygen and hydrogen, despite their exceedingly great affinity. At 350° C., mercury combines with the oxygen of the atmosphere, forming a red crystalline powder, and at 400° this powder is again decomposed into oxygen gas and mercurial vapour.

If we fuse a mixture of iron and lead, together with sulphur, in a crucible, the iron separates from the lead, and combines with the sulphur; as long as there remains any trace of iron in the lead, not a particle of sulphur combines with the lead, but only with the iron. When all the iron has combined with sulphur, that sulphur which still remains free combines with the lead. Both metals have an affinity for sulphur, but the affinity of the iron is far greater than that of the lead. Hence it happens that, as is done largely in metallurgy, when iron is fused with sulphuret of lead ore (*galena*), the lead separates in a pure metallic state, whilst the iron combines with the sulphur, for which it possesses a far greater affinity than lead. [illegible] In like manner, at a red-heat, iron decomposes cinnabar, and expels the mercury by combining with the sulphur; but in this case the affinity of iron for sulphur is not the only cause of decomposition. No one has ever seen mercury red-hot, like iron, for instance, in the smith's forge; for, whilst iron remains compact and solid at this heat, mercury is converted into an invisible vapour; its particles obtain by heat the property of assuming the gaseous form. Now, this property depends upon the tendency of the atoms of a substance to repel each other—to withdraw from each other—and substances retain this tendency in their chemical combinations. Mercury evaporates, even at the common temperature; a drop gradually passes into the atmosphere when exposed: it requires certainly a longer time than a drop of water; nevertheless, it will gradually disappear. Heat promotes this evaporation exceedingly. Cinnabar does not evaporate at the common temperature. This manifestly depends upon the circumstance that the tendency of the mercury to assume an aerial state, and to separate from the sulphur, meets with resistance. This resistance is the affinity of the sulphur, which is not to be overcome at the common temperature. Now, if the cinnabar be heated to that point at which the mercury assumes the gaseous state, not only does the affinity between the mercury and the sulphur become weakened, but, moreover, the tendency of the mercury to separate from the sulphur becomes strengthened. If any affinity, although only a weak one, come at this juncture to the assistance of the heat, that, for instance, of iron for the sulphur, the sulphur separates from the mercury, which would not have happened without the concurrence of these several causes. Thus, the tendency of a substance to assume an aerial form at a certain temperature, acts an important part in all chemical processes of combination and decomposition. It modifies, increases, or diminishes the manifestations of affinity. In precisely a similar manner, cohesive attraction—the power which the particles of a substance possess of maintaining their cohesion against all influences which tend to destroy it—has a share in the play of the affinities. We may, by the application of heat, melt sugar and common salt,—render their particles moveable in all directions,—destroy and annihilate their solid state. We may do the same by means of water; but in the water in which sugar and common salt dissolve, it is not heat, but the chemical affinity of the water, which overcomes their cohesion. A fragment of bone calcined white is insoluble in water and alkaline fluids; the tendency of its particles to maintain their state, or, as it is termed in this case, their power of cohesion, is greater than the affinity of the fluid for them. In many acid fluids, as, for example, in vinegar, the contrary is the case, the fragment of bone dissolves therein; it is, consequently, obvious that if we bring the constituents of this fragment of bone (phosphoric acid and lime) into an acid fluid, we do not observe any kind of alteration to take place, because both the constituents of the bone are soluble in the acid fluid, no matter in what form they may exist. But if these constituents are brought together in water or an alkaline fluid, which opposes no obstacle to their combination into a solid substance, we shall see the bone-earth fall to the bottom as a white powder; a *precipitate*, as it is termed, being formed.

In this manner the chemist uses the different degrees of solubility of substances in various liquids, and their deportment at a high temperature, as a powerful means of separation,—of analysis. All minerals, without exception, may be dissolved in liquids, by a proper choice of solvents. By altering the nature of the liquid, by the addition of other matters, the chemist modifies the solubility of the constituents of the mineral in this liquid, and in this manner he succeeds in separating all its constituents one by one. This is one method of analysis; the other consists in adding to the solution of a compound, consisting of five, six, or more constituents, successively, other substances, which enter into combination with one or other of those constituents, forming insoluble compounds. This is done in a certain definite order, just as if each constituent was contained in a different drawer, the opening of which required a particular key appropriated to itself.

LETTER VI.

In studying these combinations and decompositions, the question immediately arises, what is the quantity of any one given substance that is required to form a chemical compound with another? or how much of a third body is required to expel one of the constituents of that compound, and to replace it by the third? All these questions have been studied, and satisfactory answers have been returned to them, in all their various bearings. We know exactly the proportions in which bodies unite, as well as the proportions in which they replace each other in chemical compounds.

A chemical compound is characterised by this, that the proportions, by weight, of its constituents, are invariable. In this lies the distinction between such a compound and a mere mixture, in which the ingredients are present in variable and indefinite proportions. In the following lines are given the proportions, by weight, of the constituents of some chemical compounds:—

Water contains	
Oxygen	88·89
Hydrogen	11·11
	100·00

Hydrochloric acid	
Chlorine	97·76
Hydrogen	2·24
	100·00

Carburetted Hydrogen	
Carbon	85·71
Hydrogen	14·29
	100·00

Hydrosulphuric acid	
Sulphur	94·19
Hydrogen	5·81
	100·00

Hydriodic acid	
Iodine	99·21
Hydrogen	0·79
	100·00

That the constituents of a chemical compound are present in it in invariable proportions is regarded as the first and most important law of combination; so much so, indeed, that it is impossible for us to conceive water, with *the same* properties as ordinary water, but having a different proportion of hydrogen and oxygen from that above given. The observations which have led to this law belong to modern times, and it may be for this reason that, in earlier ages, when the law was unknown, chemists had very undefined notions concerning the relation between the properties of a compound and the proportions of its constituents. We now know that the properties of a compound depend on certain definite relations of weight, and these properties alter with the increase or diminution of the proportion of a constituent.

On the other hand, it must always be regarded as another important discovery, that, as experience proves, the constituents of a simple chemical compound, when they enter into other chemical compounds, replace each other exactly in the proportion in which they combine. In the composition, in 100 parts, as given above, we learn the proportion, by weight, in which this replacement occurs.

When, therefore, in a compound of oxygen, the oxygen is removed, and hydrogen is to be substituted for it, then we find always and invariably, 88·89 parts by weight of oxygen replaced by 11·11 parts by weight of hydrogen. In like manner, 2·24 parts of hydrogen, in a compound of that body, are replaced and represented by 97·76 parts, by weight, of chlorine; and 94·19 parts of sulphur by 5.81 of hydrogen.

The above results of decomposition, ascertained by analysis, may be expressed in a simple form.

To 1 part, by weight, of hydrogen there is found,

In water	In Hydrochloric acid	In Carburetted Hydrogen
8 parts of Oxygen.	35·4 of Chlorine.	6 of Carbon.

In 9 parts of water there is 1 of hydrogen. Now since this 1 part of hydrogen is replaceable by 35·4 of chlorine and 6 of carbon, it is evident that these numbers (8 oxygen, 35·4 chlorine, 6 carbon) represent also the proportions in which those bodies combine together.

In 9 parts, by weight, of water, there is 1 part, by weight, of hydrogen, removable and replaceable by

35·4 parts of chlorine. It follows that, when this replacement has taken place, there must have been formed a compound of oxygen and chlorine, an oxide of chlorine, in which 8 parts of oxygen are united with 35·4 parts of chlorine; and so with carbon, 6 parts.

1 of Hydrogen	replaced by	35·4	Chlorine,
8 Oxygen,	add Oxygen	8·	(from the water),
—		—	
9 Water,	we have	43·4	Oxide of Chlorine;

or,

1 Hydrogen	replaced by	6	Carbon,
8 Oxygen,	add	8	Oxygen (from the water),
—		—	
9 Water,	we have	14	Carbonic Oxide.

Further: since 1 part of hydrogen is replaceable by 35·4 of chlorine, it follows, that if we replace the hydrogen in 7 parts of carburetted hydrogen (containing 1 of hydrogen) by chlorine, then 6 parts of carbon unite with 35·4 of chlorine.

1 Hydrogen	replaced by	35·4	Chlorine,
6 Carbon,	add	6·	Carbon (from the Carb. Hyd.),
—		—	
7 Carb. Hydrogen,	we have	41·4	Chloride of Carbon.

We see, then, that 8 parts, by weight, of oxygen, 35·4 of chlorine, and 6 of carbon, express actually, not only the proportions in which all these bodies unite with 1 part of hydrogen, but also the proportions in which they combine among themselves; for replacement, in fact, means nothing else than combination.

This law of replacement or combination in definite and invariable proportions is true not only for the bodies just named, but for all. If, therefore, we know the proportions, by weight, in which one body combines with another, or with ten others, or with twenty, or with all other bodies, we know also the proportions, by weight, in which all these bodies mutually replace each other; that is, in which they combine among each other, one with another.

The following Table scarcely requires, after these remarks, any explanation:—

Oxygen	O	8	Potassium (kalium)	K	39·2
Hydrogen	H	1	Calcium	Ca	20·5
Carbon	C	6	Silicon	Si	14·8
Sulphur	S	16	Lead (plumbum)	Pb	103·8
Nitrogen	N	14	Copper (cuprum)	Cu	31·8
Phosphorus	P	31·4	Quicksilver (hydrargyrum)	Hg	100·0

These numbers express the proportions, by weight, in which a few simple substances combine with each other; or, if the expression please you better, the equivalent amounts in which they replace each other in their combinations. Chemists are acquainted with the combining proportions, the equivalent numbers, of all the known simple bodies.

Further, it must be especially remarked that these relative numbers do not change, even in those cases in which one body forms, with a second or with a third, more than one compound.

Thus, for instance, 14 parts of nitrogen combine with 8 parts of oxygen, and form the substance known as the laughing gas, *nitrous oxide.*

There exists another compound of these substances, also a colourless gas (*nitric oxide*), which forms red fumes when it comes into contact with atmospheric air, and which to 14 parts of nitrogen contains twice $8=16$ parts of oxygen.

A third compound contains 3 times $8=24$ parts of oxygen, with 14 of nitrogen (*nitrous acid*).

A fourth contains 4 times $8=32$ parts of oxygen to the 14 of nitrogen (*hyponitric acid*).

A fifth (*nitric acid*) contains 5 times $8=40$ of oxygen, invariably, to 14 parts of nitrogen.

I may adduce another example in the compounds of carbon and oxygen.

Carbon combines with oxygen in two proportions: the first compound, an inflammable gas (*carbonic acid*), contains 8 parts of oxygen to 6 parts of carbon; the other (*carbonic acid*) contains twice 8=16 oxygen to 6 of carbon. These fixed and invariable proportions are observed in all cases where the elementary bodies unite to form any definite compound of distinct and peculiar properties.

Again, from the analysis of acetic acid, it appears that this acid contains in 100 parts by weight, 47·06 carbon, 5·88 hydrogen, and 47·06 oxygen. These numbers in 100 parts, inform us how much oxygen and hydrogen are combined with 47·06 of carbon; and nothing is easier than the calculation for finding how much oxygen and hydrogen is in this substance combined with 6 carbon. This is a simple rule-of-three question. To 6 carbon we have in acetic acid ¾ hydrogen, and 6 of oxygen; or, to express the same in whole numbers, let us multiply by 4, and we then have 24 carbon, *i.e.*, 4 times 6; 3 hydrogen, *i.e.*, 4 times ¾; and 24 oxygen=4 times 6. Or, to look at it in another point of view, we know how much carbon and hydrogen are in acetic acid combined with 47·06 of oxygen, and we may calculate how much of these two elements are united with 8 of oxygen (that is, with another of these invariable numbers representing the simple elements); and we obtain as the result, to 8 oxygen, 1 hydrogen and 8 carbon; and this, multiplied by 3, gives us precisely the same proportions.

The composition of all chemical compounds whatever, may be expressed in the same manner, by invariable *numbers*, which on this account have been designated by the term *combining proportions*, and, with respect to their mutual power of substitution, *equivalents*; because, indeed, they express the quantities in which substances enter into admixture, or rather into chemical combination, or in which they produce equivalent effects. Or, to state this in other words, if, in order to exercise any chemical action, we require for any given purpose 8 parts of oxygen, and if, instead of the oxygen, we are able and desire to employ for the same purpose sulphur, we invariably require 16 parts of the latter body. Thus these combining proportions are the representation of equal values of effect. Hence the term *equivalent*.

CHEMICAL SYMBOLS.

The establishment of the truth of the great natural law, that all bodies capable of entering into combination always do so in definite and fixed proportions, led chemists immediately to the invention of symbolical language, which enables them to express, in an exceedingly simple manner the constitution of every compound body, the replacement of any of its elements, and, in general, the mode in which the constituents are supposed to be arranged in every compound.

This symbolical language is exceedingly simple, and you will readily obtain a complete and satisfactory knowledge of it by attending to the following illustrations :—

In the first place, chemists have agreed to designate the *elements*, and at the same time their *equivalents*, by the initial letter of the names of the elements in the Latin language. Thus, the letter O, for example (from *oxygenium*) in the symbolic language of chemistry, signifies not merely the element, oxygen, but neither more nor less than 8 parts by weight of oxygen.

H represents 1 part by weight of hydrogen ; S, 16 parts by weight of sulphur.

The vast advantages of this system are abundantly obvious. The most retentive memory would not be able to retain with accuracy and permanently the proportions, in 100 parts, of the constituents of hundreds of compound bodies, whilst by the use of symbols and formulæ nothing is easier of apprehension and recollection; thus, the composition of water, which, stated according to the per-centage of its elements, is composed of 88·889 of oxygen, and 11·111 of hydrogen, is expressed by the chemist by the letters HO; the double amount by $2\,HO$; the threefold amount, by $3\,HO$, and so on.

Carbonic oxide, which, as we have stated above, is composed of 6 carbon and 8 oxygen, is expressed by CO.

Carbonic acid, is 6 carbon, 16 oxygen, and is, therefore, written CO_2.

Acetic acid is $C_4H_3O_3$, and the combination of acetic acid and water is represented by the formula, $C_4H_3O_3 + HO$.

Ether is represented by C_4H_5O.

Alcohol, which is considered to be a combination of ether and water, by $C_4H_5O + HO$.

The full meaning of which is, four equivalents of carbon $=$ 4 times 6 parts $= 24$; five equivalents of hydrogen $= 5$ times $1 = 5$; one equivalent of oxygen $= 8$, and superadded to these an equivalent of water $= 9$, composed of one equivalent of hydrogen $= 1$, and one equivalent of oxygen $= 8$.

But the application of the term "equivalents" is extended also to compound bodies.

Among these we find many groups, the individual members of which exhibit similar properties, or analogous chemical relations and characters, and may be made to take each other's place, or function, in compounds. Every one is acquainted with the general properties of that group of substances which bears the name of ACIDS. The term *base* is, perhaps, not so universally understood. We designate compounds possessing the power of combining with acids and neutralising their acid properties, by the word BASES. A compound of an *acid* with a base is denominated a SALT (this name has no reference to the taste). Now, in these compounds—in salts—one base may be made to replace another base, one acid another acid. Many metallic oxides, or compounds of oxygen with metals, are such bases; and it has been observed, from a minute examination of the proportions in which these metallic oxides replace each other, that very unequal weights of different bases are required in this substitution. In order to expel 10 parts of one base, 15 parts of another base, or 25 parts of a third base, and so on, are necessary. If the 10 parts of the first base contain 5 parts of oxygen, we find that the 15 parts of the second, or 25 of the third base, &c., will also contain neither more nor less than 5 parts of oxygen. The amount of oxygen in the metallic bases replaced by each other, remains invariably the same; the metals alone combined with this oxygen vary in their proportions: they replace each other according to their equivalents, that is, for 39·2 of potassium, expelled from a compound, 100·0 of mercury are substituted.

Chemists have agreed to designate every quantity of a metallic oxide containing 8 parts by weight, that is, one equivalent, of oxygen, as *one equivalent of metallic oxide*, without regard to the amount of metal it may contain.

If, therefore, we once know the amount of an acid which is required to form a neutral salt with one equivalent of a base, this amount of acid remains invariably the same for an equivalent of any other base, since the other bases contain exactly the same amount of oxygen as the first, and since their mutual substitution depends exclusively upon the relative proportion of the oxygen. Chemists have also agreed to call that amount of acid required for the saturation of one equivalent of a base, *one equivalent of acid.*

When we are familiar with these facts, we can readily understand why chemists express the composition of acetic acid by the formula $C_4 H_3 O_3$, and not by $C_2 H_{1\frac{1}{2}} O_{1\frac{1}{2}}$, or any other. If we sum up the numbers indicated by these symbols ($C_4 = 4 \times 6 = 24$ carbon; $H_3 = 3$ hydrogen; $O_3 = 3 \times 8 = 24$ oxygen), we obtain as the result a total of 51. These 51 parts of acetic acid form the proportional amount (or one equivalent) of that acid which combines with one equivalent of any metallic oxide to form a salt.

This formula of an acid generally refers to one equivalent of a base, that of a base to one equivalent of an acid; the formula of any other compound invariably refers to the relative proportions in which its elements have been found to combine with the ascertained equivalent of some other substance. In many cases, however, where this is unknown, the formulæ express only the mutual relation of the composition of two or of more substances. The formula of a salt of acetic acid will consequently have to be written thus; $C_4 H_3 O_3, MO$; (M stands for 1 equivalent of any metal.) If we suppose that metal to be replaced by hydrogen, the formula will then represent a compound of acetic acid with oxide of hydrogen (water), and this, like all similar compounds of water, is called ***a hydrate.*** Its formula is $C_4 H_3 O_3, H O$, or, adding all the elements together, $C_4 H_4 O_4$. We can also represent the salt according to the last formula, thus: $C_4 \left.\begin{matrix} H_3 \\ M \end{matrix}\right\} O_4$; which represents hydrated acetic acid, in which 1 equivalent of hydrogen has been replaced by 1 equivalent of metal.

This symbolical language is of inestimable value for the comparison of the composition of various chemical compounds, and for facilitating the comprehension and expression of the alterations, transmutations, and decompositions which such bodies undergo.

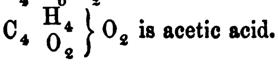
For instance, suppose I have made an analyses of acetic acid, and I am desirous to ascertain whether the numbers obtained by experiment are correct or not. For this purpose I express the amounts of carbon, oxygen, and hydrogen, which I have found, in equivalents. These have been determined with the utmost accuracy, and the nearer my numbers agree with them (this is called agreeing with the calculated result), the greater confidence I have in my analyses. If my numbers differ to any considerable degree from the equivalent numbers, I am assured there has been an error somewhere in my processes, and I have to begin my labour over again. Thus, possessing the chemical equivalent numbers of all elementary bodies, we are able to exercise a strict control over chemical analyses; the comparison of the number shows us, that we must have fallen into some error, or that the substance under investigation does not possess the necessary degree of purity.

Every one will now, I trust, be able to understand the following formulæ, and to perceive, in the subsequent simple illustrations, somewhat of their high importance and value:—

$C_{14} H_6 O_2$ oil of bitter almonds.
$C_{14} H_6 O_4$ benzoic acid.

Now, the oil of bitter almonds, the composition of which is represented by the first of these formulæ, when exposed for some time to the atmosphere, absorbs oxygen, and becomes converted into benzoic acid. The formulæ exhibit the relation between these two substances, and when translated into the numerical values, indicate exactly the quantitative change in this conversion.

Again, $C_4 H_6 O_2$ is alcohol.



$C_4 \left.\begin{matrix} H_4 \\ O_2 \end{matrix}\right\} O_2$ is acetic acid.

Alcohol is changed into acetic acid by the absorption of oxygen. But it is easy to see, by the formulæ, that the change really consists in this, that 2 equivalents of hydrogen in the alcohol have been expelled and replaced by 2 equivalents of oxygen. All this is exceedingly simple, and it will now, I trust, be easy for the reader to understand what was hinted in a former chapter, that whenever a new metal or metalloid is discovered, it is sufficient to determine how much *metal* will combine with 8 parts by weight of oxygen, or how much of the metalloid unites with 39·2 of potassium, to learn at once in what proportion it will combine with all other bodies; that is, what is its equivalent number. It is precisely thus that the equivalents of lantanium and didymium (two new metals discovered recently in the ores of cerium), and of bromine, (a new metalloid, found a few years since in sea-water), have been determined.

The creative fancy or imagination has no share whatever in these facts, or in the mutual relation of bodies, which I have here explained. Every number is the result of a large series of carefully performed analyses. But the facts, or the analyses upon which they are based, have not of themselves formed, or evolved, the great natural law which they represent and establish. The discovery of that law must be attributed to the sagacity and acuteness of a German chemist, and the name of RICHTER will remain as imperishable as the science itself.

Chem. Aff. Repulsion.

LETTER VII.

It is easy to understand that the question as to the why? as to the cause of these fixed, invariable weights in chemical compounds, must necessarily have occupied the attention of chemists. There must certainly be *some cause* which renders impossible the combination of elements in any other than certain definite proportions, *something* which opposes an invincible obstacle to any diminution or augmentation of these relative proportions.

The fixed and invariable amounts of the combining proportions or equivalents of bodies are the manifestations of this hidden cause, but these manifestations form the limit of the domain of true experimental investigation; the cause itself is beyond our powers of perception,—our sphere of research,—and can only be a subject for the exercise of speculation,—for the exercise of the reflective intellectual faculties.

In endeavouring to develope the theory which at present prevails respecting the cause of the unchangeableness of chemical proportions, let it not be forgotten, that its truth or falsehood has nothing whatever to do with the natural law itself. The latter is the expression of universal experience; it remains true, invariably and immutably, however our notions respecting its cause may, from time to time, vary and change.

A very ancient opinion respecting the nature of matter, well known as the theory of atoms, is, in truth, exceedingly well adapted to render the law of definite proportions intelligible to our understanding.

The atomic theory supposes that the space occupied by a solid, fluid, or aeriform body, is not in every part filled with matter, but that every such substance has pores, or interstices, between its particles of solid matter, which pores are not like those of a piece of wood, visible, but are of an infinitely smaller size. According to this view all bodies consist of exceedingly minute particles placed at a certain distance from each other, so that there exists between every two particles, or, rather, around every individual particle, a space not filled with the matter composing the substance itself.

It must be admitted that this view of the nature of matter is highly probable. We can compress a volume of air into a space a thousand times smaller than it originally occupied, and even fluid and solid substances are capable of being compressed into less space than they fill under ordinary circumstances, by mechanical pressure. A billiard-ball thrown with considerable force upon a hard substance becomes flattened, and, after rebounding, resumes its spherical form. All bodies expand and fill a larger space when heated, and contract into a smaller space when exposed to a low temperature.

All these well-known facts manifestly prove that the space which a body occupies at any given time depends upon accidental circumstances; that this space varies by the operation of such causes as temperature and pressure, which tend to render it greater or smaller. Now, when we reflect that the place within any body, occupied by one of its smallest particles, cannot at the same time be occupied by a second and a third particle, we cannot help drawing the conclusion that the augmentation or diminution of its volume, which we have described, is a consequence of a greater or less distance between its space-filling particles. Thus, in a pound of liquid water, the particles of the water must evidently be nearer to each other than they are in a pound of steam, which occupies a space 1700 times greater than a pound of liquid water.

This theory affords us an intelligible insight into a number of phenomena, which, although simple in themselves, have hitherto been altogether inexplicable upon any other supposition.

Again, the atomic theory presupposes that the small particles composing the mass of any substance are incapable of further division,—that they are indivisible particles or *atoms*, a term applied to the ultimate particles of bodies, derived from the Greek, *a*, *not*, and *τεμνω*, *to cut.*

It is impossible for the human mind to imagine particles of matter to be absolutely indivisible, since they cannot be infinitely small in a mathematical sense, that is to say, altogether without extension, because they possess a certain weight; and how minute soever we may assume this weight to be, yet we cannot consider the division of a particle possessing weight to be impossible, into two, three, nay into a hundred parts. But we may also suppose that the ultimate atoms of bodies are only physically indivisible; they are only incapable of further subdivision so far as our powers of perception enable us to judge.

A physical *atom* in this sense, then, is a conglomeration of innumerable smaller imaginary particles, held together by a force or forces more powerful than all the means at our command for their further subdivision or dissolution.

With respect to these atoms, and the meaning the chemist attaches to the term, it is precisely analogous to the opinion held respecting certain substances as to their being elements, or simple, uncompounded bodies.

The sixty-two substances at present known and supposed to be simple bodies or elements are so considered, not absolutely, but only relatively to our powers, because we are not able by any means we possess at present to decompose them,—that is, to separate them into still more simple elements; and, adhering to the true principles of natural philosophy, we call them simple bodies or elements, until experience shall demonstrate them to be compound.

The history of science presents us with abundant illustrations of the supreme importance of a strict adherence to this rule of philosophical inquiry,—retroression, errors, and fallacious theories innumerable, having invariably followed the transgression of the limits of experience.

Without disputing the infinite divisibility of matter, the chemist merely maintains the firm and immoveable foundation of his science, when he admits the existence of physical ATOMS as a truth, entirely incontrovertible.

A professor of Tübingen has endeavoured, by an ingenious illustration, to render the atomic theory of chemists more intelligible. He compares atoms to the heavenly bodies, which, in comparison with the extent of the space in which they are suspended, are infinitely small, that is, are *atoms*. Innumerable suns, with their planets and attendant satellites, move in infinite space, at definite and measured distances from each other; they are individually indivisible, inasmuch as there exists no force capable of separating them into parts, tearing off from them anything material, or altering their size or form in such a degree as to be perceptible, or to impair or disturb their relations to the other heavenly bodies, but they are not indivisible *per se*.

In this sense the whole universe coalesces into one immense body, the atoms of which—that is, suns, planets, and satellites—are indivisible and unchangeable!

According to the atomic theory, then, a piece of glass, of cinnabar, of iron, &c., is a heap or congeries of atoms of glass, cinnabar, iron, &c., the connection of which, in masses, depends upon the power or attraction of cohesion. The smallest particle we can imagine of the iron is still *iron*. But we know, with positive certainty, with respect to the cinnabar, that its smallest particle, although physically indivisible, is made up of still smaller particles; that is, that it must contain particles of sulphur and particles of mercury; and we further know even the relative proportions, by weight, of these two substances contained in the physically indivisible particle of cinnabar.

The iron consists of homogeneous atoms of iron; the cinnabar also consists of homogeneous atoms, each of which is cinnabar; but these latter atoms are not simple, like those of the iron, but they are capable of being separated into constituent parts: they are homogeneous as far as our senses reach, but we nevertheless know their nature to be compound. We may, by the mere mechanical processes of filing, trituration, &c., reduce a piece of cinnabar into an innumerable quantity of small particles, but no merely mechanical force will enable us to overcome that power by which the heterogeneous particles forming the constituents of a complex atom like that of cinnabar are kept united.

It is precisely in this that chemical affinity differs from the power of cohesion, or cohesive attraction, as it is called,—that it becomes active and manifest only when *dissimilar* atoms are brought into contact with each other; and since it is impossible that atoms should penetrate and become mutually diffused throughout each other, it follows that such compound atoms must be formed by the aggregation, or grouping side by side, of the simple atoms, in consequence of the power of affinity acting so as to associate them into compound atoms,—one atom of one simple body being aggregated with one, two, three, or more atoms of another body, and so on,—every such group being a part exactly analogous to the mass of a substance perceptible to our senses. Thus, we may suppose the very smallest particle of cinnabar we can imagine, consists of a group of two atoms, namely, one atom of mercury, and one atom of sulphur.

When we consider that a thousand pounds weight of cinnabar contains exactly the same relative proportions of mercury and of sulphur as a single pound, or a single grain,—and although a piece of cinnabar large enough to be manifest to our senses must contain, perhaps, millions of *atoms* of cinnabar,—yet it must be evident that in every single atom, equally as in the mass made up of millions of atoms, 100 parts by weight of mercury are invariably united to 16 of sulphur. If we decompose cinnabar by means of iron, the atom of mercury is displaced, and an atom of iron is substituted for it. Or if we replace the sulphur of the cinnabar by oxygen, one atom of oxygen takes the place of the atom of sulphur.

You will now perceive that, according to this theory of the constitution of bodies, and their mutual substitution in combinations, the numbers denominated equivalents express nothing else than the weight of the atoms. The *absolute* weight of the atom of any substance it is not within the reach of our faculties to determine; but how much more or less weight one body brings into a combination than another, that is to say, the *relative* weight of atoms, can readily be ascertained.

Since to replace 8 parts by weight of oxygen 16 parts by weight of sulphur are required, that is, double the weight of the oxygen, the atom of sulphur is twice as heavy as that of oxygen.

In substituting hydrogen for oxygen in any compound, only one-eighth part of the weight of the latter substance is required to one part of the former; it is evident that the weight of the atom of hydrogen is eight times lighter than the atom of oxygen. Carbonic oxide is a group of *two* atoms, containing one atom of carbon and one atom of oxygen. Carbonic acid is a group of *three* atoms, containing two atoms of oxygen to one of carbon.

The immutability of the proportions, by weight, in which bodies combine, is fully explained theoretically by thus assuming the existence of indivisible ultimate particles, which are of unequal weights, incapable of penetrating or being diffused through each other when they are united in chemical combination, but being arranged together side by side.

It is, however, in the highest degree expedient that you should discriminate between what is established on the sure ground of experience, and what in this subject is merely hypothetical.

The real experimental import of the equivalent numbers is the expression of the proportional and relative weight of bodies in which they produce equivalent effects in chemical combinations; and these effects we represent to our minds, and render intelligible, by ascribing them to indivisible particles, or *atoms*, which occupy a certain space, and possess a certain form, or shape. We possess no means of ascertaining the *number* of atoms, even in the most simple compound, since for this purpose it would be necessary that we should be able to see and to count them, and therefore, notwithstanding our firm conviction of the existence of physical atoms, the supposition that the equivalent numbers actually express the relative weights of the individual atoms, is only an hypothesis, for which we have no further proofs.

One atom of cinnabar contains 16 of sulphur to 100 of mercury; now chemists, in assuming that these proportions express the relative weight of *one atom* of mercury and *one atom* of sulphur, pass from experimental certainty into hypothesis; for this mode of representation is merely hypothetical. 100 of mercury may, for aught we know to the contrary, represent the weight of two, three, four, or more *atoms*. Should it represent two atoms, one atom of mercury would be expressed by 50; should it represent three atoms, one atom would be expressed by 33·3. In the first case cinnabar would consist of two atoms, twice 50, in the latter case of three atoms, thrice 33·3 of mercury, to one atom of sulphur.

Whatever supposition we may entertain in this respect, whether we assume the composition of cinnabar to require two, three, or more atoms of mercury or sulphur, its constitution remains invariably the same. It is only the method by which we represent the composition of a chemical compound to our minds, which would vary with the hypothetical view respecting the number of atoms contained in the compound. It will always be most advisable to banish all that is hypothetical from the symbolic language of chemistry, more especially as the only purpose of this language is to demonstrate to our sense of sight, to render easy of apprehension, and to facilitate the recollection of, the compositions, substitutions, transmutations, and decompositions of chemical combinations. The method of representing the constitution of compound substances ought never to be used for expressing unsettled and mutable notions or speculative theories. The number of the equivalents of the constituents of a chemical compound is invariable, and strictly definable, but the number of atoms necessary to make up an equivalent will never be ascertained. There is not, however, the slightest disadvantage in assuming that the equivalents represent the weights of the atoms themselves in cases where theoretical considerations, the mere explanation of ideas, is concerned. In this sense those numbers express merely the difference between the weights of various atoms; that is, by how much the weight of the atom of one body is heavier than that of another.

The numbers in the table given at p. 87 refer to the relative weights required to replace 1 part by weight of hydrogen, or to the replacement of the weight of oxygen which, in water, is combined with 1 part of hydrogen. Water contains 8 parts by weight of oxygen, to 1 part by weight of hydrogen. Upon the supposition, then, that water consists of a single atom of oxygen, combined with a single atom of hydrogen,—and, further, that in every conceivable combination into which these elements may enter, the replacement of one atom of hydrogen, or one atom of oxygen, invariably requires one atom of any other body, and neither more nor less,—then these equivalent weights of all other bodies express their atomic weights, and the numbers by which they are represented all refer to the assumed unit, to 1 part by weight of hydrogen, or 8 parts by weight of oxygen.

If we multiply all these equivalent numbers by 12·5, we obtain the equivalent numbers, 12·5 for hydrogen and 100 for oxygen; and the other numbers, representing the equivalents of other bodies, express the amount of each which is required to replace 100 of oxygen or 12·5 of hydrogen. The multiplication of the equivalents by one and the same number does not, of course, alter their relative proportions, and it is, therefore, quite immaterial whether we use numbers referring to hydrogen as a unit, or to oxygen as 100.

LETTER VIII.

ACCORDING to the theory which I have attempted to develope, the ultimate particles of bodies, or *atoms*, must occupy a certain space, and possess a certain definite form. By their combination with each other, compound atoms are formed, which may occupy an equal or a larger space than the simple atoms of which they are made up, taken together, in their uncombined state. The *form* of such compound atoms, it is evident, must vary with their composition, or according to the manner of arrangement of their elements. It is only in crystallisable bodies, however, the smallest molecules of which only have a definite form coming within the reach of our cognisance, that we can perceive the relation between the form of the particles of bodies and their chemical constitution. These relations have been observed, and very interesting investigations have been instituted upon this subject.

When two salts of different crystalline forms separate from the same fluid upon its evaporation, the crystals of one salt are formed precisely as they would be were the other salt not present in the fluid.

If we throw a handful of saltpetre and common culinary salt together into a sufficient quantity of water, both salts dissolve in the water. Upon placing the solution in a warm place the water gradually evaporates, and the two salts remain at the bottom of the vessel in the form of crystals, and we can distinguish with the naked eye the *cubes* of the common salt from the *long six-sided prisms* of the nitre. If we remove a crystal of the common salt from the solution, and wash off the adhering fluid from its surface, we find that it contains not the slightest trace of the saltpetre, and on the other hand the crystals of saltpetre retain not the slightest trace of common salt.

Both crystals are formed simultaneously in one and the same fluid, and, therefore, the inference is obvious that the atoms of common salt, in aggregating into crystals, attracted only atoms of common salt, whilst the atoms of the saltpetre attracted only their own kind. When all the water of the solution has been removed by evaporation, there will remain a mingled mass of common salt and saltpetre; but the individual crystals, however intimately intermixed, will remain, perfectly and distinctly, either common salt or saltpetre.

Again, if sulphate of magnesia and nitrate of potass (saltpetre) be added to a small proportion of hot water, and the saturated solution decanted, crystals of nitrate of potass and of sulphate of magnesia will form, during the refrigeration of the solution, side by side; but, as in the former case, the individual crystals of sulphate of magnesia contain no nitrate of potass, and the individual crystals of nitrate of potass contain no sulphate of magnesia. The atoms of these substances had no kind of attraction, respectively, for the atoms of the other; on the contrary, we conclude that there must exist some species of repulsion between them both; for, if it were not so, surely the atoms of the saltpetre and common salt, or sulphate of magnesia, would not merely form side by side, but would completely intermix and crystallise in alternate layers.

It is altogether different with sulphate of magnesia and sulphate of nickel, or sulphate of zinc. When sulphate of magnesia and sulphate of zinc, or sulphate of nickel, crystallise together from the same solution, the separation of the two substances, as in former instances, does not take place. The individual crystals formed will contain both sulphate of zinc and sulphate of magnesia, or sulphate of nickel and sulphate of magnesia, and this in every possible proportion, according to the relative amount of the two salts present in the solution. This manifests the existence of a mutual attraction between the atoms of these substances, which attraction is, in each salt respectively, perfectly analogous to the attraction of the other; for an atom of sulphate of zinc attracts indiscriminately another atom of the same, or an atom of sulphate of magnesia; and there is no selection made between the different atoms, as happens when common salt and saltpetre are in the same solution.

If we compare a crystal of sulphate of magnesia with a crystal of sulphate of nickel, we find that they have identically the same crystalline form. The crystal of sulphate of magnesia looks like a white sulphate of nickel; the sulphate of nickel like a *green* sulphate of magnesia. There is no difference in their forms, no perceptible distinction in their edges, angles, or solid angles, between the two crystals. Now, since a large crystal differs from a small one only by its consisting of an aggregation of smaller crystals, it is evident that the most minute,—the *ultimate* atom of sulphate of nickel, must necessarily have the same form as the most minute atom of sulphate of magnesia. Or, in other words, the *group* of elementary atoms which are united to form an atom of sulphate of zinc or sulphate of nickel, has the same form as the group constituting one atom of sulphate of magnesia; the crystal in which both are united side by side, and in alternate layers, possesses the form characteristic of both or either of its components.

But more extended observations have proved that the analogy between the crystalline forms of two substances is not the only cause of their crystallising together, or of the form of those crystals, wherein two salts are mixed, being the same as the form of their constituents.

Thus, a crystal of sal ammoniac possesses the same geometrical form as a crystal of alum, but these salts separate unmixed from solutions; the crystals of alum which are formed contain no sal ammoniac, and the crystals of sal ammoniac no alum. This happens, evidently, because the force with which alum atoms attract alum atoms, and sal ammoniac atoms sal ammoniac atoms, is far greater than the power of attraction which operates between atoms of sal ammoniac and atoms of alum, notwithstanding the identity of their crystalline forms. Indeed, as far as our observation extends, no such attraction in this case exists.

If we compare the chemical constitution of those compounds which, notwithstanding the identity of their crystalline forms, yet do not crystallise in alternate layers or in mixed crystals, with the constitution of those substances which, under similar circumstances, enter into the same crystal, we find that the composition of the former is altogether diverse, whilst the composition of the latter is analogous in every respect. Thus, sulphate of magnesia, sulphate of zinc, and sulphate of nickel, contain exactly the same number of compound atoms; indeed, a crystal of sulphate of magnesia differs from a crystal of sulphate of zinc or sulphate of nickel, only inasmuch as the two latter, instead of one equivalent or atom of magnesium, contain one atom of nickel or of zinc; so that we may convert one into the other by separating the metallic equivalent of one salt by, and replacing it with, another. The atom of sal ammoniac contains only two compound atoms, whilst the atom of alum, although of the same crystalline form, is made up of thirty compound atoms. It is impossible to imagine a more dissimilar constitution, and these substances do not form mixed crystals when crystallised at the same time from the same solution.

Very numerous experiments and investigations have proved that analogy of chemical constitution in two bodies is generally attended with an analogous crystalline form, and, moreover, that two compounds possessing the same form of crystallisation, and separating together from solutions in mixed crystals having the same geometrical form as either substance by itself, have for the most part a strictly analogous constitution; that is, they contain the same number of atoms, or equivalents, arranged in the same manner.

In cases where two salts, of dissimilar crystalline forms, crystallise together, we invariably find the form of the mixed crystal is similar to the form of one of the two salts, and its composition is analogous to that of the salt, the form of which it has taken. Thus, from a mixed solution of sulphate of copper and sulphate of zinc, two salts of different forms and dissimilar composition, we obtain, by evaporation, mixed crystals, possessing either the form of sulphate of copper or that of sulphate of zinc, as the one or the other predominates in the solution; and we find that the constitution of the former is similar to sulphate of copper, and of the latter to sulphate of zinc.

The most striking illustrations of the fact that the similarity of the crystalline forms of many compounds is entirely independent of the diversity of their elements, are afforded by a group of salts called *alums*, by which term we designate compounds possessing a constitution similar to that of common alum. The constituents of this latter substance are sulphuric acid, alumina, potass, and water; it crystallises in large and regular octahedrons. Now, we may separate the alumina from this alum, and replace it by an equivalent of sesquioxide of iron, oxide of chromium, or sesquioxide of manganese, without causing any other alteration in its composition or form. The iron alum, which contains peroxide of iron instead of alumina, is colourless, and by its external appearance is not to be distinguished from the original alumina alum; and the chromium and manganese alums do not differ from ordinary alum, except in colour, the former being of a dark green, by reflected, a deep red by transmitted light, the latter of a violet hue.

If a crystal of chrome alum is thrown into a cold saturated solution of common or alumina alum, the atoms of the latter, separating during the gradual evaporation of the water, will dispose themselves upon the surfaces of the crystal of chrome alum. If the crystal be turned every day so as to insure an uniform increase upon its several faces, a regular octahedron of white and transparent alumina alum will be obtained, having in its centre, as a nucleus, a regular octahedron of chrome alum, of a deep ruby red by transmitted light.

In the same manner we may separate the sulphuric acid from the alum, and replace it by chromic acid, or selenic acid, both acids possessing a constitution perfectly analogous to sulphuric acid.

We may also substitute soda or ammonia (oxide of ammonium) for potass in the alum, without altering its form of crystallisation; and experience has proved, that not only in this instance of the alum, but in all cases where alumina, peroxide of iron, oxide of chromium, peroxide of manganese or sulphuric acid, chromic acid, and selenic acid, or potass and ammonia, replace each other in compounds, the form of the new compound is the same as that of the original compound. It is only in cases where a new constituent, in consequence of these substitutions, is added, or one of the original constituents is separated, that we find the form of the resulting crystal different from the first, because the *composition* in that case becomes altered.

Chemists have at length become acquainted with all those substances which replace each other in analogous combinations without changing the form of crystallisation, and have arranged them into groups. These bodies have received the appropriate designation of *isomorphous* (similiform). Thus, we denominate chlorine, bromine, iodine, cyanogen, fluorine,—or, again, lime, magnesia, protoxide of iron, protoxide of manganese,—*isomorphous*: by which we mean that those of their compounds which are analogous in constitution have the same crystalline form, and that these substances are capable of replacing each other in combinations without altering the form of their crystals. You will find no difficulty in understanding that a crystal of alum may contain peroxide of iron and alumina, or potass and ammonia, in perfectly indefinite and variable proportions, without ceasing on that account to be a crystal of alum, or to be considered one. It is involved in the characteristic property of isomorphous substances not to replace each other in certain definite and immutable proportions, but in all possible proportions. This appeared at first sight to stand opposed to the universality of the acknowledged laws of fixed and constant combining proportions. But the knowledge of the ultimate cause, that is, of the analogous form and like attraction of the particles of isomorphous bodies, explains it in the most simple and satisfactory manner.

This beautiful discovery, made by a German philosopher, Mitscherlich, has the most important and significant bearings upon mineralogy. When attempting to arrange minerals according to their constituents and composition, innumerable difficulties and perplexities arose. The most conscientious chemists contradicted each other as to the components of minerals presenting the most characteristic properties. Thus, while one found in the garnet of Arendal above 13 per cent. of magnesia, this was wholly wanting in the garnets of Fahlun, of Vesuvius, &c. In the noble garnet, analysts detected 27 per cent. of alumina, whilst not a trace of this substance was found in the yellow garnet of Altenau. What, then, are the constituents of garnet? Of what substance is it composed? This is now explained in a very simple manner. Where there was no alumina the isomorphous peroxide of iron was found; where the magnesia was absent, the isomorphous lime was found. It became evident that garnet contains varying amounts of isomorphous oxides, such as peroxide of iron and alumina or lime, protoxide of iron or protoxide of manganese, which are capable of replacing each other without altering the form of the resulting compound.

More minute and accurate admeasurements of the crystals have, however, subsequently shown that the similar combinations of isomorphous substances have not invariably the same form *exactly*,—that the angles which the sides of the crystals form with each other are not identically the same. Such crystals are called plesiomorphous. One of the most cogent arguments for the soundness of our views respecting the existence of atoms is, that these deviations are explicable upon certain considerations attaching to the atomic theory.

Let us imagine a crystal formed by the arrangement, side by side, of atoms, each of which possesses a certain shape, and the form of the crystal to be dependent upon the form of its constituent atoms. For instance, alum. The alumina atom will occupy a certain definite space within the atom of alum. If we remove the atom of alumina from this crystal and substitute in its stead an atom of peroxide of iron, the crystal of alum will retain its original geometrical form, if the atom of peroxide of iron has the same *form* as the atom of alumina. But the form of the crystal of alum will remain absolutely the same only if the peroxide of iron atom is of exactly the same *size*,—if its volume be identical with the volume of the atom of alumina. But wherever the atom of the isomorphous body does not exactly fill the space occupied by the atoms to be displaced—*i. e.*, if its volume be smaller or larger—this will manifest itself in the inclination of the edges of the crystal towards its axis.

A very ingenious method has been devised for enabling us to compare the space which the atoms of two isomorphous substances, replacing each other in a combination, occupy. Every one knows that equal volumes of solid, fluid, and gaseous substances differ very much in weight. We quite involuntarily compare the relative space which a piece of wood and a piece of lead of equal weight occupy, by saying that the wood is lighter than the lead. A pound of wood weighs exactly as much as a pound of lead, but a cubic inch of lead weighs more than eleven times heavier than a cubic inch of wood. This difference of weight between equal volumes of different substances has been examined with great accuracy, and expressed in numbers. The designation *specific gravities* is given to these numbers. Now, in order to compare the *absolute weight* of two substances, we ascertain how many times a definite and known unit of weight, as a *pound*, for example, is contained in the mass of each, without any regard to their volume ; and it has been agreed in like manner to determine the specific weights or gravities of substances by means of a unit of weight of a definite and known volume. How much a given volume of any substance is heavier than an equal volume of another substance, is expressed by numbers referring to the weight of an equal volume of water. The weight, then, of a given volume of water is adopted as the standard,—the *unit* of the specific gravities of all other substances. The number, therefore, designating the specific gravity or weight of a substance, expresses how many times heavier or lighter than an equal volume of water is a given volume of the substance ; that is, how many times the weight of the unit is contained therein.

In order to ascertain the absolute weight of any substance, we place it upon one scale of the balance, and upon the other scale we place as many units of weight (pounds or ounces, for example,) as will restore the perfect equilibrium of the balance. It is quite immaterial whether these units of weight consist of lead, iron, platinum, wood, or any other substance. Let us suppose that instead of iron, or other metallic weight, we had a pound or an ounce weight of water. If we place the substance, the weight of which we wish to ascertain, upon one scale, and as much water as will restore the equilibrium of the balance perfectly in the other, we obtain the weight of the substance represented in pounds or ounces of water. If we now compare the volume of the substance under examination with the space occupied by an equal weight of water, we know at once and with accuracy how much more or less space an equal weight of water occupies than the equal weight of the weighed substance; in other words, we ascertain its *specific gravity*.

Thus, if we place upon one scale of the balance a cubic inch of iron, we require on the other scale 7¾ cubic inches of water to restore perfectly the equilibrium. One cubic inch of water, therefore, is 7¾ times lighter than a cubic inch of iron, one cubic inch of iron is 7¾ times heavier than a cubic inch of water.*

If we place upon one side of the balance 100 given volumes of oil of turpentine, and upon the other as much water as is required to restore the equilibrium of the balance perfectly, and then measure this water, it will be found that 86 volumes of the water are as heavy as the 100 volumes of oil of turpentine, or 86 volumes of oil of turpentine occupy the same space as 100 volumes of water; or again, as we may also express it, a given measure of oil of turpentine weighs only $\frac{86}{100}$ of an equal volume of water.

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* It may be well to mention, *en passant*, in what manner we ascertain the volume of such substances as cannot be measured by our ordinary instruments, as, for example, *sand*. The volume of sand, or of similar substances, may be determined with the greatest accuracy by the following method:—Take a glass tube, carefully graduated, to denote its capacity in cubic inches, every cubic inch being again divided into 100 parts. Fill this tube to half its capacity with water, and project into it a weighed amount of sand, or of the substance under examination. The water will rise in the tube. The difference in the level of the water thus produced indicates exactly the volume of the sand in cubic inches, and $\frac{1}{100}$ths of a cubic inch.

The numbers 7·75 for the specific gravity of iron, 11·3 for lead, 1·989 for sulphur, 4·498 for iodine, 1·38 for fluid chlorine, scarcely require any further explanation; they express how many times iron, lead, sulphur, iodine, fluid chlorine, weigh more than an equal volume of water. The difference in weight between two equal volumes of sulphur and iron, for example, presents relations precisely analogous to the difference between the numbers 1·989 and 7·75; that between equal volumes of iodine and chlorine is like that of the numbers 4·948 and 1·380, and so with the others.

The difference of weight between two substances of equal volumes remains, of course, invariably the same, however minute or extensive one may assume these volumes to be. Whenever the amount of the volume of one body is increased or decreased,—as, for instance, doubled, the relative proportion must still be preserved in the numbers expressive of the specific gravities. The difference of weight between two cubic inches of iodine and one cubic inch of fluid chlorine, is expressed by $2 \times 4{\cdot}948 = 9{\cdot}896$ and 1·380, &c.

Now, it will be obvious to you that there is some *cause* upon which this difference of weight between equal volumes of different substances depends, and this cause is very satisfactorily explained upon the theory of the constitution of bodies which we have adopted. According to this view, every substance consists of an aggregation of ponderable particles, or atoms, each of which occupies a certain space, and possesses a certain definite form.

Our knowledge of isomorphous bodies establishes indisputably the fact that their mutual substitution in combinations, without changing the crystalline form of the compound, depends upon the circumstance that their respective atoms possess one and the same form and size. Whenever the crystalline form of a compound is altered by substituting one element for another, we may be assured that the alteration in the form of the crystal is in consequence of the atoms of the replacing body having another form than the atom of the substance replaced, or its not occupying the same space in the combination. These facts, taken in connection, lead us to the conclusion that the ultimate particles of bodies which we denominate *atoms* are of unequal magnitude or unequal weight. If we once admit this conclusion, it explains the specific gravity of bodies in a very simple and satisfactory manner. The reason, according to these preliminary data, that a given volume of lead is heavier than an equal volume of iron, iron heavier than sulphur, iodine heavier than an equal volume of chlorine, must be either that the *atom* of iodine is heavier than the atom of chlorine, &c., or that a portion of lead, for instance, contains in the same bulk a greater number of atoms than iron.

Let us suppose an equal number of atoms, say 1000, of iodine or chlorine, to be comprised within the space of one cubic inch, it is obvious that the specific gravities of these two substances express the difference of weight between their respective atoms. If the cubic inch of iodine weighs 4948 grains, and the cubic inch of chlorine 1380, then $\frac{1}{1000}$th of the cubic inch of iodine, containing one atom of iodine, would weigh 4·948, and $\frac{1}{1000}$th of a cubic inch of chlorine, containing one atom of chlorine, would weigh 1·380 grains.

Chlorine and iodine replace each other in chemical compounds according to their equivalents, that of chlorine being 35·4, that of iodine 126. Moreover, they are isomorphous substances; that is, they replace each other in compounds of analogous constitution, without change in the crystalline form. If we now assume their atoms to be of the same size and the same form, and if in equal volumes of iodine and chlorine an equal number of atoms of these substances are contained, their specific gravities must stand in the same relative proportion to each other as their equivalent numbers or their atomic weights.

Exactly 1·380 grains of chlorine ought, on this supposition, to be required to displace and replace 4·948 grains of iodine. A simple rule-of-three calculation proves at once that this is really the case. The numbers which represent the specific gravities of chlorine and iodine, namely, 1·380 and 4·948, are to each other in the same proportion as their equivalent numbers, 35·4 and 126.

This remarkable relation has been found to extend to all isomorphous substances, and thus a physical property of bodies, namely, specific gravity, has unexpectedly been drawn into the sphere of chemical philosophy. The numbers expressing the specific gravities of bodies are equally expressive of the relative proportions in which they replace each other in combinations; that is to say, identically the same proportions which are found to exist between their equivalent numbers. Whenever there is found to be any diversity in isomorphous substances, that is, whenever the specific gravities do not exactly correspond in this respect with their equivalent numbers, the difference manifests itself in the inclination of the faces of their crystals; in the angles, for instance, which the edges form with the axis of the crystal. The form of the crystals is identically the same only when the atoms of isomorphous substances replacing each other have the same *volume*, together with the same *form*. Whenever the volume of the replacing atom is less in magnitude than that of the displaced atom, this will be perceptible in the form of the resulting crystal.

In order to compare, by means of numbers, the volumes which the atoms of different substances occupy, the following method has been devised.

Let us suppose the equivalent numbers to be real weights: let us assume, for instance, the number

35·4, for chlorine, to signify 35·4 ounces of chlorine; the number 126, for iodine, 126 ounces of iodine; 28, for iron, 28 ounces; 29·6, for nickel, 29·6 ounces of nickel; and let us divide each of these numbers by the weight of one cubic inch of chlorine, iodine, iron, nickel, or, what is the same thing, by the numbers representing their specific weights.

Assuming one cubic inch of water to weigh one ounce, one cubic inch of chlorine will weigh 1·380 ounces; one cubic inch of iodine, 4·948 ounces; one cubic inch of iron, 7·790 ounces; one cubic inch of nickel, 8·477 ounces. Taking these numbers (the specific gravities) as the divisors, the quotients will represent the number of cubic inches of chlorine, iodine, nickel, or iron, which are contained in one equivalent of each of these substances. In other words, we are informed by the resulting numbers how much space relatively to each other an equivalent of chlorine, iodine, nickel, and iron, respectively occupies; or, expressing it generally, the relative proportion which the volume of bodies bears to their equivalents or atomic weights.

Now, the atoms of isomorphous substances are, according to our supposition, of the same form and of equal size,—their number is equal in equal volumes. If, therefore, there are exactly the same number of atoms in one equivalent of chlorine as in one equivalent of iodine, we must, by dividing their atomic weights by their specific gravities, necessarily obtain as the quotient the same number.

The atomic weight of chlorine, 35·2, divided by its specific gravity, 1·380, gives 25; and the atomic weight of iodine, 126, divided by its specific gravity, 4·948, gives us precisely the same number, 25.

It is easy to perceive that, admitting our data, it cannot be otherwise. The atomic weights or equivalent numbers of isomorphous bodies, *must*, when divided by the number representing their specific gravities, give identically the same quotient, precisely because they contain in equal volumes an equal number of atoms ; and if, therefore, these atoms are not the same in size and form, the differences will be manifested in the quotients obtained.

A knowledge of the numbers representing the volumes of different bodies is of great importance in enabling us to perceive their mutual relations. They have been designated by the terms *atomic volumes* or *specific volumes*. Thus we say the atomic volume of chlorine is 25, that of iodine is also 25 ; both the numbers being the same, the substances themselves are isomorphous. The atomic volume of sulphur is 8, —very different from that of chlorine, with which substance sulphur is not isomorphous ; but it is the same as that of selenium, with which, therefore, sulphur is isomorphous.

The accurate determination of the numbers representing the atomic volumes of substances is of the highest importance, since they enable us to perceive, at the first glance, what substances possess an equal or unequal number of atoms in equal volumes ; and thus their mutual relations may be compared and understood.

LETTER IX.

When we would speak of the progress and development of modern chemistry, we cannot avoid passing an eulogium on the means and implements employed by the chemist in his labours. Without glass, cork, platinum, and caoutchouc, we should probably, at this day, have advanced only half as far as we have done. In the time of Lavoisier, only a few, and those very rich persons, were able, on account of the costliness of apparatus, to make chemical researches.

Every one is familiar with the wonderful properties of glass. Transparent, hard, colourless, unchanged by acids and most other liquids, and, at certain temperatures, more plastic and flexible than wax, it takes, in the hands of the chemist, and in the flame of a proper lamp, the form and shape of every piece of apparatus required for his experiments.

What precious properties are combined in cork! How little can any but chemists appreciate its value and recognise its good qualities! We might cudgel our brains in vain, in the hope of replacing cork, as the ordinary means of closing bottles, by any other substance whatever. Let us imagine a soft, highly elastic mass, which nature herself has impregnated with a matter of properties resembling wax, tallow, and resin, yet dissimilar to all of these, and termed *suberin*. This renders it perfectly impermeable to fluids, and, in a great measure, even to gases. By means of cork, we connect wide apertures with narrow ones; with cork and caoutchouc we connect our vessels and tubes of glass, and construct the most complicated apparatus with the aid of the brass-founder and the mechanist, of screws and stopcocks. Thus the implements of the chemist are cheaply and easily procured, immediately adapted to any purpose, and readily repaired or altered.

Without platinum, it would be impossible, in many cases, to make the analysis of a mineral. The mineral must be dissolved, and it must be first rendered soluble, or prepared for solution. Now, vessels of glass, of porcelain, and of all non-metallic substances, are destroyed by the means we employ for that purpose. Crucibles of gold and silver would melt at high temperatures. But platinum is cheaper than gold, harder and more durable than silver, infusible at all temperatures of our furnaces, and is left intact by acids and alkaline carbonates. Platinum unites all the valuable properties of gold and of porcelain, resisting the action of heat, and of almost all chemical agents.

As no mineral analysis could be made perfectly without platinum vessels, had we not possessed this metal, the composition of minerals would have yet remained unknown; without cork and caoutchouc we should have required the costly aid of the mechanician at every step. Even without the latter of these adjuncts our instruments would have been far more costly and fragile; but the chief advantage derived from these substances is the economy of our time—to us more precious than money!

Such are our instruments. An equal improvement has been accomplished in our laboratory. This is no longer the damp, cold, fireproof vault of the metallurgist, nor the manufactory of the druggist, crowded with stills and retorts. On the contrary, a light, warm, comfortable room, where beautifully constructed lamps supply the place of furnaces, and the pure and odourless flame of gas, or of spirits of wine, supersedes coal and other fuel, and gives us all the fire we need.

To these simple means must be added "The Balance," and then we possess everything which is required for the most extensive researches.

The great distinction between the manner of proceeding in chemistry and natural philosophy is, that one *weighs*, the other *measures*. The natural philosopher has applied his measures to nature for many centuries, but only for fifty years have we attempted to advance our philosophy by *weighing*.

For the great discoveries of Lavoisier, he was indebted to the "balance"—that incomparable instrument which gives permanence to every observation, dispels all ambiguity, establishes truth, detects error, or shows us that we are in the true path.

The balance, once adopted as a means of investigating nature, put an end to the reign of Aristotle in physics. The explanation of natural phenomena by mere fanciful speculations, gave place to a true natural philosophy. Fire, air, earth, and water, could no longer be regarded as elements. Three of them could henceforth be considered only as significative of the *forms* in which all matter exists. Everything which exists upon the surface of the earth is now, as it was formerly, solid, liquid, or aëriform ; but the notion of the elementary nature of Air, Earth, and Water, so universally held, now fell into the domain of history.

Fire was found to be but the visible and otherwise perceptible indication of changes in the forms of bodies.

Lavoisier investigated the composition of the atmosphere and of water, and studied the many wonderful offices performed by an element common to both in the scheme of nature, namely, *oxygen:* and he discovered many of the properties of this elementary gas.

After his time, the principal problem of chemical philosophers was to determine the composition of the solid matters composing the earth. To the eighteen metals previously known were soon added thirty-two discovered to be constituents of minerals. The great gulf between oxygen and the metals was found to be filled by a series, gradually passing from one to the other. The great mass of the earth was shown to be composed of two or more *oxides,* of fixed and invariable composition ; of compound minerals, consisting, on the one hand, of metallic oxides, united, on the other, with oxides, whose radicals, silicon or carbon, differed essentially from metal. Another less abundant class of minerals consisted of compounds of sulphur, sulphurets, or sulphides, in which sulphur played the part of the oxygen in the compound oxides above mentioned. With the exception of one chloride (rock salt, the chloride of sodium,) the amount of the remaining mineral compounds in the crust of the earth, such as fluorides, arsenurets, selenurets, iodides, &c., was, in comparison to that of the oxides, sulphurets, and chloride above named, quite insignificant.

Mineral chemistry, however, was not satisfied with the separation of minerals into their component elements, *i. e.* their analysis; but it formed, for instance, by synthesis, pumice-stone, feldspar, mica, iron pyrites, &c., artificially.

But of all the achievements of inorganic chemistry, the artificial formation of lapis lazuli was the most brilliant and the most conclusive. This mineral, as presented to us by nature, is calculated powerfully to arrest our attention by its beautiful azure-blue colour, its remaining unchanged by exposure to air or to fire, and furnishing us with a most valuable pigment, Ultramarine.

Ultramarine was dearer than gold; it seemed impossible to form it, for analysis had sought in vain for the colouring ingredient. It was shown to be composed of silica, alumina, and soda, three colourless bodies, with sulphur and a trace of iron, neither of which are blue; and no other body had been detected in it, to which its colour could be ascribed. Yet, now, simply by combining in the proper proportions, as determined by analysis, silica, alumina, soda, iron, and sulphur, thousands of pounds weight are now manufactured from these ingredients; and this artificial ultramarine is even more beautiful than the natural, while for the price of a single ounce of the latter we may obtain many pounds of the former.

With the production of artificial lapis lazuli, the formation of mineral bodies by synthesis ceased to be a scientific problem to the chemist. Whether it should cease to occupy the attention of geologists, who can doubt? but it will be a long time before geologists make up their minds to try experiments, which are no longer to be expected from chemists, because they have no longer a scientific interest in them. In this respect there is no longer a question for the chemist to solve.

After becoming acquainted with the constituent elements of all the substances within our reach and the mutual relations of these elements, the remarkable transmutations to which bodies are subject under the influence of the vital powers of plants and animals, became the principal object of chemical investigations, and the highest point of interest. A new science, inexhaustible as life itself, is here presented us, standing upon the sound and solid foundation of a well-established inorganic chemistry. Thus the progress of science is, like the development of nature's works, gradual and expansive. After the buds and branches spring forth the leaves and blossoms, after the blossoms the fruit.

Chemistry, in its application to animals and vegetables, endeavours jointly with physiology to enlighten us respecting the mysterious processes and sources of organic life.

LETTER X.

In the preceding chapter I pointed out that the elements of the ancients only serve as symbols, to represent the forms or states in which all the ponderable matter of our globe exists. I would now observe that no substance possesses absolutely any one of those conditions; that modern chemistry recognises nothing unchangeably solid, liquid, or aëriform. Platinum, alumina, and rock crystal, it is true, cannot be liquefied by the most intense heat of our furnaces, but they melt like wax before the flame of the oxyhydrogen blowpipe. On the other hand, of the twenty-eight gaseous bodies with which we are acquainted, twenty-five may be reduced to a liquid state, and nine even into that of a solid. Probably, ere long, similar changes of condition will be extended to every form of matter.

There are many things relating to this condensation of the gases worthy of your attention. Most aëriform bodies, when subjected to compression, are made to occupy a space which diminishes in the exact ratio of the increase of the compressing force. Very generally, under a force double or triple of the ordinary atmospheric pressure, they become one half or one third their former volume. This was a long time considered to be a law, and known as the law of Marriotte; but a more accurate study of the subject has demonstrated that this law is by no means of general application. The volume of certain gases does *not* decrease in the ratio of the increase of the force used to compress them; but in some, a diminution of their bulk takes place in a *far greater degree* as the pressure increases.

Again, if ammoniacal gas is reduced by a compressing force to one-sixth of its volume, or carbonic acid is reduced to one thirty-sixth, a portion of them loses entirely the form of a gas, and becomes a liquid, which, when the pressure is withdrawn, assumes again in an instant its gaseous state,—another deviation from the law of Marriotte.

The means employed by the discoverer (Faraday) for reducing gases into fluids are of admirable simplicity. A simple bent tube, or a reduction of temperature by artificial means, have superseded, in his hands, the most powerful compressing machines.

The cyanuret of mercury, when heated in an open glass tube, is resolved into cyanogen gas and metallic mercury; if this substance is heated in a tube hermetically sealed, the decomposition occurs as before, but the gas, unable to escape, and shut up in a space several hundred times smaller than it would occupy as gas under the ordinary atmospheric pressure, becomes a fluid in that part of the tube which is kept cool.

When sulphuric acid is poured upon limestone in an open vessel, carbonic acid escapes with effervescence as a gas, but if the decomposition is effected in a strong, close, and suitable vessel of iron, we obtain the carbonic acid in the state of liquid. In this manner it may be obtained in considerable quantities, even many pounds weight. Carbonic acid, when separated from other bodies with which it is combined, under a pressure of thirty-six atmospheres, appears not as a gas, but as a liquid.

The curious properties of liquid carbonic acid are now generally known. When a small jet of it is permitted to escape into the atmosphere, it assumes its gaseous state with extraordinary rapidity, and deprives the remaining fluid of heat so rapidly that it congeals into a white crystalline mass like snow: at first, indeed, it was thought to be really snow, condensed from the surrounding air; but upon examination it proved to be pure frozen carbonic acid, the temperature of which was at least eighty degrees below that of freezing water.

At this low temperature, carbonic acid behaves like snow; like snow, it may be exposed to a higher temperature, without its own temperature, as long as any solid matter is left, rising above a certain limit; namely, that of its melting point. Exposed to the air, solid carbonic acid, in the form of snow, evaporates continually, though slowly, when compared with the behaviour, under similar circumstances, of the liquid, that is, warmer carbonic acid. For the tendency of a body to assume the gaseous form is not so much a property of its material substance as of the amount of heat in it. Solid carbonic acid, therefore, can only evaporate in proportion as it receives heat from without.

When exposed to the air, nay, when thrown into a red-hot capsule, it retains, while continually evaporating, its solid form (in that which has not yet evaporated), and, so long as it retains the solid form, it retains also its low temperature (its melting point). The more rapid addition of heat hastens its evaporation, but produces no other change on the portion which remains solid.

If we take solid, snow-like carbonic acid in the hand or between the fingers, we perceive but little of its intense cold, because, in consequence of its light, spongy, porous structure, like that of dry flakes of snow, it offers very few points of contact with the skin, and hence can withdraw from it but little of its heat.

But if we press the solid acid with some force on the skin, the circulation of the blood is arrested at the point touched, as by a metal at a dull red-heat; a white spot appears, which in fifteen seconds becomes a blister, and in two minutes a white depression is formed, followed by suppuration and healing, a scar being left.

The white solid snow of carbonic acid is moistened by ether, when that liquid is poured on it, and communicates its very low temperature to the ether, as well as to all bodies moistened with the mixture. Ten, twenty, or more pounds of mercury, when covered with this mixture of ether and solid carbonic acid, become in a few seconds solid and malleable. When the mixture of ether and solid carbonic acid is placed in the vacuum, there is produced, in consequence of the increased and accelerated evaporation, so intense a degree of cold (from 180° to 200° below the freezing point of water on Fahrenheit's scale, or from 100° to 110° below that point on the scale of Celsius, or the centigrade scale) that most of the compound gases become liquid when exposed to it, and several are frozen (Faraday).

The first and most important condition of a rapid passage of heat into a solid body, like snow (or like the carbonic acid in its snowy form) or of a rapid subtraction of heat from the surrounding bodies, is that the snow or carbonic acid should be moistened, so as to spread over the solid on which it lies. The spreading of a drop of water on a glass plate, on wood, or on metal, and its adhesion to those bodies depends on a chemical attraction between the particles at the surface of the solid body and those of the water, which is obviously stronger than the attraction between the particles of the liquid themselves. Were the latter the more powerful attraction, the liquid would preserve its spheroidal form, and would not moisten the solid body. For this reason, quicksilver spreads out upon tin, like water on wood, while on glass it retains the form of spheroidal drops.

On the same principle we explain the striking phenomenon, called Leidenfrost's experiment. A drop of cold, or still better, of boiling hot water, sprinkled on a red hot plate of iron, dances about on it, retains its spheroidal shape, and, since it does not moisten the plate, receives from it but little heat. Its evaporation is, under these circumstances, singularly retarded.

It is easy to see the cause of this phenomenon. The temperature of the metal may be raised far above redness, but that of water, in the open air, cannot rise above its boiling point. As the temperature of the iron rises, the mutual attraction between its particles, and that between them and the particles of the water, diminish; and while the attraction between the particles of the iron and those of the water diminishes, the mutual attraction between the particles of the water remains unchanged, because its temperature no longer rises. At a certain temperature of the iron, this latter attraction (between the particles of the water themselves) comes to predominate, and the metal is no longer moistened. When the metal is no longer moistened, the passage of heat from the red-hot iron to the liquid is arrested, or nearly so. All volatilisable liquids, under similar circumstances, behave as water does. Liquid sulphurous acid, when poured into a red-hot silver or platinum crucible, retains its spheroidal state; its temperature does not rise beyond its boiling point, and, as this is 10° Celsius (18° Fahrenheit) below the freezing point of water, we can actually freeze water by pouring it into the sulphurous acid in a red-hot crucible. The same thing occurs with a mixture of sulphurous acid or ether and solid carbonic acid, when introduced into a red-hot metallic vessel. The mixture requires, for its conversion into gas, as much time as it would in the air at the ordinary temperature. If we introduce into this mixture, whether contained in a vessel at the ordinary temperature, or in the red-hot crucible, a small tube containing a little mercury, the mercury freezes and becomes solid.

It is well known that we may introduce the hand if moist (or slightly moistened) into melted lead, nay, into white-hot melted copper or iron, and move it slowly about in these liquids, not only without burning the hand, but without even feeling the intense heat of the melted metals; whereas iron or copper at a heat far below redness, instantly cause a blister or a burn. On this fact depended the trick played by the priests of old in the ordeal of fire. They occupied the place of a jury, and knew how to convince the multitude of the guilt or innocence of the accused.

The liquefaction of gases cannot be accomplished without considerable danger. A melancholy accident occurred at Paris, which proved the extreme danger of the preparation of liquid carbonic acid by the action of sulphuric acid on bicarbonate of soda, which is accompanied by a strong disengagement of heat. Just before the commencement of the lecture in the Laboratory of the Polytechnic School, a cast-iron cylinder, two feet and a half long and one foot in diameter, in which carbonic acid had been developed for experiment before the class, burst, and its fragments were scattered about with the most tremendous force; it cut off both the legs of the assistant, and the injury was followed by his death. We can scarcely think, without shuddering, of the dreadful calamity which the explosion of this vessel, formed of the strongest cast-iron, and shaped like a cannon, would have occasioned in a hall filled with spectators, and yet the apparatus had been often used for the same experiments, which naturally banished all idea of danger.

By conducting the disengagement of the gas and its condensation in two separate vessels, the preparation of the liquid carbonic acid becomes quite free from danger. The gas is first collected in a gas holder, and is then condensed by means of a common condensing air pump or syringe, into a strong vessel of malleable iron, capable of resisting a pressure more than ten times as great as that of the liquid carbonic acid; namely, thirty-six atmospheres, without bursting.

When we had ascertained the fact of gases becoming fluid under the influence of cold or pressure, a curious property possessed by charcoal, that of absorbing gas to the extent of many times its volume, —ten, twenty, or even as in the case of ammoniacal gas or muriatic acid gas, eighty or ninety fold,— which had been long known, no longer remained a mystery. Some gases are absorbed and condensed within the pores of the charcoal, into a space several hundred times smaller than they before occupied; and there is now no doubt they there become fluid, or assume a solid state. As in a thousand other instances, chemical action here supplants mechanical forces. *Adhesion* or heterogeneous attraction, as it is termed, acquired by this discovery a more extended meaning; it had never before been thought of as a cause of change of state in matter; but it is now evident that the adhesion of a gas to the surface of a solid body is a process opposite to that of solution.

The smallest amount of a gas,—atmospheric air for instance,—can be compressed into a space a thousand times smaller by mere mechanical pressure, and then its bulk must be to the least measurable surface of a solid body, as a grain of sand to a mountain. By the mere effect of mass,—the force of gravity,—gaseous molecules are attracted by solids and adhere to their surfaces; and when to this physical force is added the feeblest chemical affinity, the liquefiable gases cannot retain their gaseous state. The amount of air condensed by these forces upon a square inch of surface is certainly not measurable; but when a solid body, presenting, by means of its pores, several hundred square feet of surface within the space of a cubic inch, is brought into a comparatively small volume of gas, we may understand why that volume is diminished, why all gases without exception are absorbed. A cubic inch of beech-wood charcoal must have, at the lowest computation, a surface of one hundred square feet.

This property of absorbing gases varies with different kinds of charcoal: it is possessed in a higher degree by those containing the most pores, *i. e.* where the pores are finer; and in a lower degree in the more spongy kinds, *i. e.* where the pores are larger.

In this manner every porous body—rocks, stones, the clods of the fields, &c.—imbibe air, and therefore oxygen; the smallest solid molecule is thus surrounded by its own atmosphere of condensed oxygen; and if in their vicinity other bodies exist which have an affinity for oxygen, a combination is effected. When, for instance, carbon and hydrogen are thus present, they are converted into nourishment for vegetables,—into carbonic acid and water. The development of heat when air or watery vapour is absorbed, or when the earth is moistened by rain, is acknowledged to be the consequence of this condensation by the action of surfaces.

But the most remarkable and interesting case of this kind of action is the absorption of oxygen by metallic platinum. This metal, when massive, is of a lustrous white colour, but it may be brought, by separating it from its solutions, into so finely divided a state, that its particles no longer reflect light, and it forms a powder as black as soot. In this condition it absorbs more than eight hundred times its volume of oxygen gas, and this oxygen must be contained within it in a state of condensation greater than that of liquid water.

In the state of condensation, in which oxygen exists on the surface of metallic platinum, its peculiar properties are developed in a remarkable degree; and the same is true of all gases, which have the same relation to the platinum. Their chemical characters become apparent as their physical characters disappear. The latter consists in the continual tendency of their particles to separate from each other, on which again depends their property of filling entirely the space which they occupy. Now, since chemical action only takes place when the material particles exerting chemical attraction are in a certain degree of proximity, it is easy to see that the elasticity of gases is one chief impediment to the manifestation of their chemical affinities. The property possessed by the gaseous particles of repelling each other is the exact opposite to what we call attraction; for this becomes more energetic as their particles approximate. Gases, when condensed within the pores or upon the surface of solid bodies, exhibit a very highly intensified chemical action. Thus combinations which oxygen cannot enter into, decompositions which it cannot effect while in the state of gas, take place with the greatest facility in the pores of platinum containing condensed oxygen. In finely pulverised platinum, and even in spongy platinum, we in fact possess a *perpetuum mobile*—a mechanism like a watch which runs out and winds itself up—a force which is never exhausted —competent to produce effects of the most powerful kind, and self-renewed *ad infinitum.*

When hydrogen gas is allowed to flow on the surface of spongy platinum, the pores of which contain condensed oxygen, we see the platinum become red-hot, while the jet soon takes fire. This striking phenomenon depends on the formation of water, which goes on in the pores. The hydrogen gas, which does not combine with uncondensed oxygen gas unless a flame be applied, combines immediately and directly with the condensed oxygen. Water is thus formed, and the immediate result of this formation of water, of the oxidation or slow combustion of hydrogen, is a development of heat, whereby the process is accelerated, more heat is developed, and the platinum becomes red hot. It then, like any other red hot body, sets fire to the jet of hydrogen. The heat is the result of the formation of water, the kindling of the jet subsequently is the consequence of the high temperature produced. If we interrupt the jet, the pores of the platinum are again filled, in an instant of time, too short to be measured, with new portions of condensed oxygen, and the same phenomenon may be repeated a second time, and so on *ad infinitum.*

Metallic platinum acts towards many combustible gases in the same way as towards hydrogen gas; it effects their combination with oxygen, and increases their combustibility. Many gases, not by themselves combustible in the air, undergo combustion readily when mixed with oxygen, and conducted over hot spongy platinum. One of the most remarkable combustions of this kind is that of ammoniacal gas. This gas, composed of nitrogen and hydrogen, is entirely burnt or oxidised under these circumstances; its hydrogen yielding water, and its nitrogen the highest stage of oxidation of that element, the compound known as nitric acid.

When sulphur is burned in a vessel full of air, there is formed a gaseous compound of sulphur with the oxygen of the air, which is well known as *sulphurous acid,* the cause of the peculiar suffocating smell of burning sulphur. When to this acid we add half as much oxygen as it already contains, along with a certain amount of water, there is formed the body called *sulphuric acid,* so valuable and important in the arts. In the manufacture of sulphuric acid, or oil of vitriol, as it is called, from sulphur, it is the air which yields all the oxygen required. But the gaseous sulphurous acid, which is alone produced when sulphur burns, will not combine directly with more oxygen from the air to form sulphuric acid. The oxygen of the air, however, readily combines indirectly with the sulphurous acid, when the latter is in certain loosely held together forms of combination. If, for example, we add sulphurous acid to spring water, or river water, containing, as it does, some dissolved oxygen, the sulphurous acid, combining with that oxygen, passes into sulphuric acid. In like manner, when sulphur is burned in wine-casks, the oxygen taken up by the wine from the air during the filling of the casks is seized by the sulphurous acid, and the formation of vinegar is thus prevented. Platinum acts in a way similar to that in which the water and wine act; when placed in a mixture of oxygen gas and sulphurous acid gas, it enables the oxygen, by condensing that gas in its pores, to combine with the sulphurous acid, and form sulphuric acid.

When we conduct a mixture of these gases over spongy platinum heated to low redness in a glass tube, the vapour of anhydrous sulphuric acid flows out at the other end, producing, in moist air, thick white clouds, which are the hydrated acid formed by the combination of the moisture of the air with the dry sulphuric acid.

In the actual manufacture of oil of vitriol, nitric oxide gas plays a part analogous to that of the platinum. Nitric oxide is that well-known oxide of nitrogen (deutoxide) which forms red vapours (nitrous acid) when mixed with air; since it has the property, rare among gases, of directly combining with gaseous oxygen. When oxygen and moisture are present in sufficient quantity, the nitric oxide is converted into nitric acid. Now, when sulphurous acid is brought into contact with nitric acid and water, the nitric acid is reduced to the state of nitric oxide, the oxygen lost by the nitric acid converting the sulphurous acid into sulphuric acid. It is evident that the nitric oxide, being liberated, and totally unchanged, may serve again, and any number of times, for the same purpose. With air and moisture it will again form nitric acid, which, in contact with a new portion of sulphurous acid, will again yield sulphuric acid and nitric oxide. It is easy to perceive how one and the same portion of nitric oxide may convert into sulphuric acid unlimited quantities of sulphurous acid, without ever losing its power to do so; since, ultimately, its action, like that of spongy platinum, consists in taking oxygen from the air and transferring it to the sulphurous acid. When all the sulphurous acid is converted into sulphuric acid, the nitric oxide remains as such, or in the form of a higher oxide of nitrogen. In the manufactories of oil of vitriol sulphur is burnt, and the sulphurous acid gas, mixed with air, is conducted into long chambers lined with lead. Here the current of gases is mixed with nitric acid and the vapour of water. Nitric oxide is set free (the nitric acid yielding oxygen to the first portion of sulphurous acid), and by its means all the sulphurous acid, in its passage through the chambers, is converted into sulphuric acid, as above explained. It is only when air, that is, oxygen is deficient in the chamber, that a loss of sulphuric acid is sustained. When enough of air is present, the nitric oxide escapes in the form of nitrous acid, and can, by means of proper arrangements, be collected and returned into the chambers repeatedly.

With the aid of platinum we can not only convert ammonia into nitric acid, but we can also reconvert the oxides of nitrogen, and other gaseous compounds of nitrogen, into ammonia. When these oxides are mixed with hydrogen gas, and brought in contact with hot spongy platinum, their elements now combine with hydrogen, their oxygen forming water, their nitrogen ammonia.

This is the more important, because nitrogen and hydrogen do not combine *directly* to form ammonia. We are not yet acquainted with any case in which a direct combination of these gaseous elements can be effected, that is, without the presence and aid of some third body. The uncombined, elastic state, opposes combination; but, once chained, these elements follow every impulse given to them. Elements, when combined, possess different properties from those which they exhibit when uncombined; because, when they enter into combinations, they necessarily lose many of those properties which acted as impediments to their chemical action. The simple change from the gaseous form in the oxygen, or other gas, condensed in the pores of platinum, gives to it properties which it does not possess in the free state. When nitric oxide is converted into ammonia, as above, its oxygen unites with hydrogen to form water; as always happens under similar circumstances. Its nitrogen also unites with hydrogen to form ammonia; which does not otherwise happen. But this nitrogen is not ordinary, free, elastic nitrogen gas; it is nitrogen in the *nascent state;* that is before it has become free.

In many cases we are able to cause two bodies to unite, which, when both are free, do not directly combine if we bring them together at the moment when one or both are in the act of separating from some previous combination. The state in which they are at that moment is called by chemists the *status nascens*, or nascent state; and the knowledge of the methods by which bodies can be made to act on one another in their nascent state is one of the most important requisites of the art of producing new compounds in general.

It has been found that a number of other bodies possess the same properties as platinum, although in a less degree. Even powdered porcelain or common pumice stone effect the combination of oxygen with hydrogen to form water, and of sulphurous acid and oxygen to form sulphuric acid, at temperatures in which these results would not otherwise take place.

Many phenomena, formerly inexplicable, are satisfactorily explained by these recently discovered properties of solid, and especially of porous bodies. The metamorphosis of alcohol into acetic acid, by the process known as the quick vinegar manufacture, depends upon principles, at a knowledge of which we have arrived by a careful study of these properties.*

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* This mode of manufacturing vinegar consists essentially of allowing diluted alcohol to trickle through casks filled with small twigs or shavings, presenting a large surface of porous matter, where the alcohol is oxidised by the air in contact with it, and flows out below, when the process is well conducted, as vinegar. This "Schnellessigfabrication" is one of the most important branches of agricultural manufacture in many parts of the continent. It is hardly necessary here to remind the reader of the application of the principles above developed to the effects produced or producible on the gases and vapours of the air when in contact with the porous mass of the soil and the organic matters present in it, as having a most important bearing on agriculture, as alluded to already on p 132.—W. G.

LETTER XI.

THE manufacture of soda from common culinary salt, may be regarded as the foundation of the extraordinary impulse given to improvement in every department of modern industry; and we may take it as affording an excellent illustration of the dependence of the various branches of human industry and commerce upon each other, and their relation to chemistry.

Soda, properly carbonate of soda, or rather its chief constituent, the alkali, has been used in France from time immemorial in the manufacture of soap and glass, two chemical productions which employ and keep in circulation an immense amount of capital. The quantity of soap consumed by a nation would be no inaccurate measure whereby to estimate its wealth and civilisation. Political economists, indeed, will not give it this rank; but whether we regard it as joke or earnest, it is not the less true, that, of two countries, with an equal amount of population, we may declare with positive certainty, that the wealthiest and most highly civilised is that which consumes the greatest weight of soap. This consumption does not subserve sensual gratification, nor depend upon fashion, but upon the feeling of the beauty, comfort, and welfare, attendant upon cleanliness; and a regard to this feeling is coincident with wealth and civilisation. The rich in the middle ages who concealed a want of cleanliness in their clothes and persons under a profusion of costly scents and essences, were more luxurious than we are in eating and drinking, in apparel and horses. But how great is the difference between their days and our own, when a want of cleanliness is equivalent to insupportable misery and misfortune!

Soap is one of those manufactured products, the money value of which continually disappears from circulation, and requires to be continually renewed. It is one of the few substances which, like tallow and oil, are entirely consumed by use, leaving no product of any worth. Broken glass and bottles are by no means absolutely worthless; for rags we may purchase new cloth, but soap-water has no value whatever in our households. The attempt has been made, in great washing establishments, to collect the soap-water, and to separate from it the fatty acids of the soap by sulphuric acid. When these fatty acids are heated so as to destroy their impurities, they may now be used for an inferior kind of soap. But this restores only a small fraction of what is used in our household economy. It would be interesting to know accurately the amount of capital involved in the manufacture of soap; it is certainly as large as that employed in the coffee trade, with this important difference as respects Germany, that it is entirely derived from our own soil.

France formerly imported soda from Spain,—Spanish soda being of the best quality—at an annual expenditure of twenty to thirty millions of francs. During the war with England the price of soda, and consequently of soap and glass, rose continually; and all manufactures suffered in consequence.

The present method of making soda from common salt was discovered by Le Blanc at the end of the last century; but he did not receive the great prize, offered by Napoleon, for the invention. The restoration interfered; it had more pressing debts, and refused to acknowledge this one. It was a rich boon for France, and became of the highest importance during the wars of Napoleon. In a very short time it was manufactured to an extraordinary extent, especially at the seat of the soap manufactories. Marseilles possessed, but only for a time, a monopoly of soda and soap. The hatred of the population of that city, embittered by the loss, under Napoleon, of its principal source of profit, the trade in soda, came, by a singular combination of circumstances, to be serviceable to the government which followed.

In order to prepare the soda of commerce (which is the carbonate) from common salt, it is first converted into Glauber's salt (sulphate of soda). For this purpose 80 pounds weight of concentrated sulphuric acid (oil of vitriol) are required to 100 pounds of common salt. The duty upon salt checked, for a short time, the full advantage of this discovery; but when the British Government repealed the duty, and its price was reduced to its minimum, the cost of soda depended upon that of sulphuric acid.

The demand for sulphuric acid now increased to an immense extent; and, to supply it, capital was embarked abundantly, as it afforded an excellent remuneration. The origin and formation of sulphuric acid was studied most carefully; and from year to year, better, simpler, and cheaper methods for making it were discovered. With every improvement in the mode of manufacture, its price fell; and its sale increased in an equal ratio.

Sulphuric acid is now manufactured in leaden chambers, of such magnitude that they would contain the whole of an ordinary-sized house. As regards the process and the apparatus, this manufacture has reached its acmé—scarcely is either susceptible of improvement. The leaden plates of which the chambers are constructed, requiring to be joined together with lead (since tin or solder would be acted on by the acid), this process was, until lately, as expensive as the plates themselves;

but now, by means of the oxyhydrogen blowpipe, the plates are cemented together at their edges by mere fusion, without the intervention of any kind of solder, and so easily that a child might perform the operation.

And then, as to the process: according to theory, 100 pounds weight of sulphur ought to produce 306 pounds of sulphuric acid; in practice 300 pounds are actually obtained; the amount of loss is therefore too insignificant for consideration.

Again, saltpetre being indispensable in making sulphuric acid, the commercial value of that salt had formerly an important influence upon the price of the acid. It is true that 100 pounds of saltpetre only are required to 1000 pounds of sulphur; but its cost was four times greater than an equal weight of the latter. All this has likewise been changed.

Travellers had observed, near the small seaport of Yquique, in the district of Atacama, in Peru, an efflorescence covering the ground over extensive districts. This was found to consist principally of nitrate of soda. Commerce, which, with its polypus arms, embraces the whole earth, and everywhere discovers new sources of profit for industry, took advantage of this discovery. The quantity of this valuable salt proved to be inexhaustible, as it exists in beds extending over more than 200 square miles. It was brought to England at less than half the freight of the East India saltpetre (nitrate of potassa); and as, in the chemical manufacture neither the potash nor the soda were required, but only the nitric acid, in combination with the alkali, the soda-saltpetre of South America supplanted the potash-saltpetre of the East, in an incredibly short time. The manufacture of sulphuric acid received a new impulse; its price was much diminished without injury to the manufacturer; and, with the exception of fluctuations caused by the impediments thrown in the way of the export of sulphur from Sicily, it soon became reduced to a minimum, and remained stationary.

Potash-saltpetre is now only employed in the manufacture of gunpowder; it is no longer in demand for other purposes; and thus, if Government effect a saving of many hundred thousand pounds annually in gunpowder, this economy must be attributed to the increased manufacture of sulphuric acid.

We may form an idea of the amount of sulphuric acid consumed, when we find that 5000 cwts. are made by a small manufactory, and from 20,000 to 60,000 cwts. by a large one annually. This manufacture causes immense sums to flow annually into Sicily. It has introduced industry and wealth into the arid and desolate districts of Atacama. It has enabled Russia to extract platinum from its ores at a moderate and yet remunerating price; since the vats employed for concentrating this acid are constructed of this metal, and cost from 1000*l.* to 2000*l.* sterling. It leads to frequent improvements in the manufacture of glass, which continually becomes cheaper and more beautiful, being now made chiefly from soda and not from potashes. It enables us to return to our fields all their potash—a most valuable and important manure—in the form of ashes, by substituting soda in the manufacture of glass and soap.

It is impossible to trace all the ramifications of this tissue of changes and improvements resulting from one chemical manufacture; but I must still claim your attention to a few more of its most important and immediate results. I have ~~already told~~ you, ~~that~~, in the manufacture of soda from culinary salt, it is first converted into sulphate of soda. In this first part of the process, the action of sulphuric acid produces fuming. concentrated muriatic acid to the extent of one-and-a-half times or twice the amount of the sulphuric acid employed. At first, the profit upon the soda was so great, that no one took the trouble to collect the muriatic acid: indeed it had no commercial value. A profitable application of it was, however, soon discovered: it is a compound of chlorine, and this substance may be obtained from it purer and more cheaply than from any other source. The bleaching power of chlorine has long been known; but it was only employed upon a large scale after it was obtained from this residuary muriatic acid, and it was found that in combination with lime it could be transported to distances without inconvenience. Thenceforth it was used for bleaching cotton; and, but for this new bleaching process, it would scarcely have been possible for the cotton manufacture of Great Britain to have attained its present enormous extent,—it could not have competed in price with that of France and Germany. In the old process of bleaching, every piece had to be exposed to the air and light during several weeks in the summer, and kept continually moist by manual labour. For this purpose, meadow land, eligibly situated, was essential. Now, a single establishment near Glasgow, of only moderate extent, bleaches 1400 pieces of cotton daily, throughout the year. What an enormous capital would be required to purchase land for this purpose! How greatly would it increase the cost of bleaching to pay interest upon this capital, or to hire so much land in England! This expense would scarcely have been felt in Germany. Besides the diminished expense, the cotton stuffs bleached with chlorine suffer less in the hands of skilful workmen than those bleached in the sun; and already the peasantry in some parts of Germany have adopted it, and find it advantageous.

Another use to which cheap muriatic acid is applied, is the manufacture of glue from bones. Bone contains from 30 to 36 per cent. of earthy matter—chiefly phosphate of lime, and the remainder is gelatine. When bones are digested in muriatic acid they become transparent and flexible like leather, the earthy matter is dissolved, and after the acid is all carefully washed away, pieces of glue of the same shape as the bones remain, which are soluble in hot water, and adapted to all the purposes of ordinary glue, without further preparation.

Another important application of sulphuric acid may be adduced; namely, to the refining of silver and the separation of gold, which is always present in some proportion in native silver. Silver, as it is usually obtained from mines in Europe, contains in 16 ounces, 6 to 8 ounces of copper. When used by the silversmith, or in coining, 16 ounces must contain in Germany 13 ounces of silver, in England about 14½. But this alloy is always made artificially by mixing pure silver with the due proportion of the copper; and for this purpose the silver must be obtained pure by the refiner. This he formerly effected by amalgamation, or by cupelling it with lead; and the cost of this process was about 2*l.* for every hundred-weight of silver. In the silver so prepared, about $\frac{1}{1200}$ to $\frac{1}{2000}$th part of gold remained; to effect the separation of this by quartation, with nitric acid, was more expensive than the value of the gold; it was therefore left in utensils, or circulated in coin, valueless. The copper, too, of the native silver, was lost to the possessor. But the $\frac{1}{1000}$th part of gold, being about one and one half per cent. of the value of the silver, now covers the cost of refining, and affords an adequate profit to the refiner; so that he effects the separation of the copper, and returns to his employer the whole amount of the pure silver, as well as the copper, without demanding any payment; he is amply remunerated by that minute portion of gold. The new process of refining is a most beautiful chemical operation: the granulated metal is boiled in concentrated sulphuric acid, which dissolves both the silver and the copper, leaving the gold nearly pure, in the form of a black powder. The solution is then placed in a leaden vessel containing metallic copper; this is gradually dissolved, and the silver precipitated in a pure metallic state. The sulphate of copper thus formed is also a valuable product, being employed in the manufacture of green and blue pigments.

The gold obtained in this method of purification is not yet pure. After being purified, by boiling with carbonate of soda, and subsequent treatment with nitric acid, from the sulphate of lead, oxide of iron, and sulphuret of copper mixed with it; it contains, in 1000 parts, 970 of gold, 28 of silver, and, as Pettenkofer has lately shown, platinum, as a never-failing ingredient to the amount of about 2 per 1000. The two latter metals are easily separated from the gold by fusion with bisulphate of soda and saltpetre.

It would exceed the proper limits of this sketch were I to pursue all the applications of sulphuric acid, of hydrochloric (muriatic) acid, and of soda, to their minutest ramifications. But it could hardly be supposed that the beautiful stearine (stearic acid) candles, which form so good a substitute for wax lights, and the useful and cheap phosphorus matches (lucifers), should ever have come into use, but for the extraordinary improvements in the manufacture of sulphuric acid. Twenty-five years ago, the present prices and extensive applications of sulphuric and muriatic acids, of soda, phosphorus, &c., would have been considered utterly impossible. Who is able to foresee what new and unthought-of chemical productions, ministering to the service and comforts of mankind, the next twenty-five years may produce?

After these remarks, you will perceive that it is no exaggeration to say, we may judge, with great accuracy, of the commercial prosperity of a country from the amount of sulphuric acid it consumes. In this point of view, there is no manufacture worthy of greater attention on the part of governments. The reason why England resorted to such stringent measures against Naples, on account of the trade in sulphur, was simply the important influence which the price of sulphur exercises upon the cost of production of bleached and printed cotton stuffs, soap, glass, &c.; and remembering that Great Britain supplies America, Spain, Portugal, and the East with these, exchanging them for raw cotton, silk, wine, raisins, indigo, &c. &c., and that London, the seat of government, is also the chief seat of the wine and silk trade, we can understand the efforts made by the English Government to abolish the sulphur monopoly, which the government of Naples attempted recently to establish. Nothing could be more opposed to the true interests of Sicily than such a monopoly; indeed, had it been maintained a few years, it is highly probable that sulphur, the source of her wealth, would have been rendered perfectly valueless to her. Science and industry form a power to which it is dangerous to present impediments. It was not difficult to foresee that the issue would be the entire cessation of the exportation of sulphur from Sicily. In the short period the sulphur monopoly lasted, fifteen patents were taken out for methods to obtain back the sulphuric acid used in making soda. Before the monopoly in sulphur, no one thought of trying to recover the sulphuric acid; and admitting that these fifteen experiments were not perfectly successful, there can be no doubt it would ere long have been accomplished, and the reaction that must have ensued in regard to the sulphur trade must be obvious to the most prejudiced. Moreover, in gypsum (sulphate of lime), and in heavy-spar (sulphate of barytes), we possess mountains of sulphuric acid; in galena (sulphate of lead), and in iron pyrites, we have no less abundance of sulphur. As the price of sulphur rose, men began to think of obtaining the sulphur of these minerals for commercial purposes.

The problem was, how to render them, in the cheapest way, available in the manufacture of suphuric acid. Hundreds of thousands of pounds weight of sulphuric acid were prepared from iron pyrites while the high price of sulphur consequent upon the monopoly lasted. We should probably ere long have triumphed over all difficulties, and have obtained sulphuric acid from gypsum. The impulse has been given, the possibility of the process proved, and it may happen in a few years that the inconsiderate financial speculation of Naples may deprive her of that lucrative commerce. In like manner, Russia, by her prohibitory system, has lost much of her trade in tallow and potash. One country purchases only in cases of absolute necessity from another, which excludes her own productions from her markets. Instead of thousands of tons of tallow and linseed oil of Russia, Great Britain now uses thousands of tons of palm oil and cocoa-nut oil from other countries. Precisely analogous is the result of the combinations of workmen against their employers, which have led to the construction of many admirable machines for superseding manual labour. In commerce and industry every imprudence carries with it its own punishment; every oppression, every impediment to free intercourse, immediately and most sensibly recoils upon the head of those from whom it emanates.

LETTER XII.

EVERY one will agree in this, that it must be regarded as a great blessing to society that every new idea which can be presented in the form of an useful machine, or of an object of industry and trade, finds adherents who devote to its realisation their powers and talents, as well as their fortunes. For even when these are expended upon objects wholly incapable of realisation,—nay, even when the idea which first gave the impulse proves in the end to be altogether impracticable or absurd, yet, notwithstanding, other valuable and useful results are obtained by these exertions. It is with industry, in this respect, as with science; theories lead to experiments and investigations. But the man who labours in this way will scarcely ever fail to make discoveries. He digs, for example, to find wood-coal, and discovers a bed of rock-salt; or he looks for iron, and finds other and more valuable ores.

At the present moment, electro-magnetism, as a moving power, is engaging great attention and study; wonders are expected from its application to this purpose. According to the sanguine expectations of many persons, it will shortly be employed to put into motion every kind of machinery; and, amongst other things, it will be applied to impel the locomotive engines on railroads, and this at so small a cost, that expense will no longer be matter of consideration. England is to lose her superiority as a manufacturing country, inasmuch as her vast store of coals will no longer avail her as an economical source of motive power. "We," say the German cultivators of this science, "have cheap zinc, and how small a quantity of this metal is required to turn a lathe, and consequently to give motion to any kind of machinery!"

Such expectations may be very attractive; indeed they must be so, otherwise no one would occupy himself with them; and yet they are altogether fallacious; they are illusions, depending on the fact that those who entertain them have not made the necessary comparisons and calculations.

With a simple flame of spirits of wine, under a proper vessel containing boiling water, a small carriage of 200 to 300 pounds weight can be put into motion, or a weight of 80 to 100 pounds may be raised to a height of 20 feet. The same effects may be produced by dissolving zinc in dilute sulphuric acid in a certain apparatus. This is certainly an astonishing and highly interesting discovery; but the question to be determined is, which of the two processes is the least expensive?

In order to answer this question, and to judge correctly of the hopes entertained from this discovery, let me remind you of what chemists denominate "equivalents." These are certain unalterable values of effect which are proportionate to each other, and may therefore be expressed in numbers. Thus, if we require 8 pounds of oxygen to produce a certain effect, and we wish to employ chlorine for the same effect, we must employ neither more nor less than 35½ pounds weight. In the same manner, 6 pounds weight of carbon (in the form of coal) are equivalent to 32 pounds weight of zinc. The numbers representing chemical equivalents express, in the most general sense, the relative values or amounts of effect, and are applicable to every kind of effect which bodies can produce.

If zinc be combined in a certain manner with another metal, and submitted to the action of dilute sulphuric acid, it is dissolved in the form of an oxide;

it is in fact burned (oxidised) at the expense of the oxygen contained in the conducting liquid. A consequence of this action is the production of an electric current, which, if conducted through a wire, renders it magnetic. In thus effecting the solution of a pound weight, for example, of zinc, we obtain a definite amount of force adequate to raise a given weight one inch, and to keep it suspended; and the amount of weight it will be capable of suspending will be the greater the more rapidly the zinc is dissolved.

By alternately interrupting and renewing the contact of the zinc with the acid, and by very simple mechanical arrangements, we can give to the iron an upward and downward or a horizontal motion; thus producing the conditions essential to the motion of any machinery.

Out of nothing, no kind of force can arise. We know that, in this case, the moving force is produced by the oxidation of the zinc; and, setting aside the name given to the force in this case, we know that its effect can be produced in another manner. If we were to burn the zinc under the boiler of a steam-engine, consequently in the oxygen of the air instead of in the galvanic pile, we should produce steam, and by it a certain amount of force. If we should assume (which, however, is not proved) that the quantity of force is unequal in these cases,—that, for instance, we had obtained double or triple the amount in the galvanic pile, or that in this mode of generating force less loss is sustained,—we must still recollect that zinc can be represented by an equivalent weight of carbon (as coal). According to the experiments of Despretz, 6 pounds weight of zinc, in combining with oxygen, develope no more heat than one pound of coal; consequently, under equal conditions, we can produce six times the amount of force with a pound of coal as with a pound of zinc. It is therefore obvious that it would be more advantageous to employ coal instead of zinc, even if the latter produced four times as much force in a galvanic pile, as an equal weight of coal by its combustion under a boiler. Indeed, it is highly probable, that if we were to burn under the boiler of a steam-engine the quantity of coal required for smelting the zinc from its ores, we should produce far more force than the whole of the zinc so obtained could originate in any form of apparatus whatever.

Heat, electricity, and magnetism are equivalent to each other, just as carbon, zinc, and oxygen are. By a certain measure of electricity we produce a corresponding proportion of heat or of magnetic power, equivalent to each other and to the electricity producing them; we purchase that electricity with chemical affinity, which in one shape produces heat, in another electricity or magnetism. A certain amount of affinity produces an equivalent of electricity, in the same manner as, on the other hand, we decompose equivalents of chemical compounds by a definite measure of electricity. The cost of the magnetic force is, therefore, in this case, the cost of the chemical affinity. Zinc and sulphuric acid yield us chemical affinity in one form; coals, with a due supply of air, in another.

It is true that, with a very small expenditure of zinc, we can make an iron wire a magnet capable of sustaining a thousand pounds weight of iron. Let us not allow ourselves to be misled by this: such a magnet could not raise a single pound weight of iron two inches, and therefore could not impart motion. The magnet acts like a rock, which, while at rest, presses with a weight of a thousand pounds upon its support: it is like an enclosed lake, without an outlet and without a fall. But it may be said, we have, by mechanical arrangements, given it an outlet and a fall. True; and this must be regarded as a great triumph of mechanics; and I believe it is susceptible of further improvements, by which greater force may be obtained. But it remains certain that, with the exception perhaps of the boiler, nothing in our machines will be altered on this account, and that, even with our present form of boiler, one pound of coal, under the boiler of a steam-engine, will give motion to a mass several hundred times greater than a pound of zinc in the galvanic pile.*

Our experience of the employment of electro-magnetism as a motory power is, however, too recent to enable us to foresee the ultimate results of contrivances to apply it; and, therefore, those who have devoted themselves to solve the problem of its application should not be discouraged, inasmuch as it would undoubtedly be a most important achievement to enable us to avoid the danger of explosions, even at double their expense.

Professor Weber, of Göttingen, has thrown out a suggestion, that if a contrivance could be devised to enable us to convert at will the wheels of the steam-carriage into magnets, we should be enabled to ascend and descend acclivities with great facility. This will some day bear its fruits.

The employment of the galvanic pile as a motory power, however, must, like every other contrivance, depend upon the question of its relative economy: probably some time hence it may so far succeed as to be adopted in certain favourable localities; it may

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* According to a statement in the supplement to the "Allgemeine Zeitung," No. 214, (1849?) Jacobi, in the course of 1848 and 1849, has constructed an electro-magnetic machine, by means of which a boat containing twelve men could be set in motion, and the effect of which was estimated as equal to raising 24,000 lbs. to the height of one foot in one minute: but this effect cannot be compared to that of even the smallest steam-engine; since it amounts to only $\frac{4}{5}$ths of one horse-power (one horse-power = 500lbs. raised one foot in one second).—J. L. Then comes the question of the cost of this power, which apparently has not been stated, but is probably very considerable.—W. G.

stand in the same relation to steam power as the manufacture of beet sugar bears to that of cane, or as the production of gas from oils and resins to that from mineral coal.

The history of beet-root sugar affords us an excellent illustration of the effect of prices upon commercial productions. This branch of industry seems at length, as to its processes, to be perfected. The most beautiful white sugar is now manufactured from the beet-root, in the place of the treacle-like sugar, having the taste of the root, which was first obtained; and instead of 3 or 4 per cent., the proportion obtained by Achard, double or even treble that amount is now produced. And notwithstanding the perfection of the manufacture, it is probable that it will ere long be in most places entirely discontinued.

The financial laws of continental states have selected sugar as an article to be taxed on importation; and the governments of the states forming the German Customs Union (Zollverein) received, as duty on 1,200,000 cwts. of sugar, imported in 1846, 10,500,000 florins (875,000*l.*), which made a part of the sum required for the expenditure of these states. In the same year ninety-six manufacturers of beet-root sugar in the union produced 334,320 cwts. of sugar, from 4,446,469 cwts. of beet-root, and this sugar was consumed within the union at the same price as the sugar imported from tropical countries. Had this beet-root sugar not been produced at home, an equal weight of sugar would have been imported. In that case, the state would have received 2,400,000 florins (120,000*l.*) at the rate of 8¾ florins per cwt.,* which sum was paid to the manufacturers of beet-root sugar in the price of the sugar. Instead, therefore, of about

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* The manufacturers formerly paid a tax of one thaler (three shillings) on 20 cwt. of beet-root; now they pay two thalers, on the supposition that 20 parts of beet-root yield 1 part of sugar; but they obtain one part of sugar from 14 or 15 of beet-root.

13 millions of florins, which the state would then have received, it received only 10½ millions; and it is plain that without the deficit of about 2½ millions, other taxes might have been diminished to that extent. The inhabitants of the union, therefore, paid 2½ millions of florins to the beet-root sugar manufacturers, and 2½ millions in other taxes. Each of the ninety-six manufacturers received, on an average, about 25,000 florins (2000*l.*) from the population, without the latter having derived any advantage whatever from the payment. The satisfaction of eating sugar grown on our own soil is therefore purchased by a not inconsiderable sacrifice. Were all the sugar now consumed in the union produced at home, the deficit in the revenue would amount to 8½ millions. Whether it would be possible, under these circumstances, to raise 17 millions of florins in the shape of taxes within the union,—namely, 8½ millions for the manufacturers of beet-root sugar, and a like sum for the other taxes, which could be spared were all the sugar imported, —is a question which we may here leave unanswered.

Let us imagine that the states, in order to supply us with sugar, had to keep up, at an expense of 8½ millions of florins annually, raised in the form of taxes, a prodigious hot-house for the growth of the sugar-cane, and we shall soon see that the discovery of an island where the sugar-cane grows wild, and can be cultivated easily and at a trifling expense, would be hailed as a most fortunate event, especially if that island undertook to supply our whole demand for sugar at such prices as would enable us to save the whole outlay for our hot-house. Every man would profit, because the taxes could be, without any loss or disadvantage whatever, reduced to the extent of 8½ millions of florins.

It may be urged, that the manufacture of beet-root sugar has a future; that, if fully developed, it might acquire sufficient vigour to supply the annual expense incurred by the hot-house, and that it would then yield to the state, in a tax, as much as the manufacturers receive from the consumers. But this is hardly probable; for the future belongs, not to the beet-root sugar, but to the cane sugar.

On an acre of the best land, for which a yearly rent of 50 florins (about 4*l.* 3*s.* 6*d.*) is paid, there is obtained, in the environs of Magdeburg, on an average, 10 cwt. of sugar, costing in coals for its manufacture, besides the wages of labour, the price of 40 cwt. of coals. The beet-root contains 10 per cent. of sugar, and of this 7½ per cent. are obtained. The possible improvement, therefore, can only refer to the obtaining of 2½ per cent. of sugar, now lost.

An acre of land in the colonies, the rent of which is less than one-tenth of the rent in Europe, yields annually from 315 to 350 cwt. of sugar-cane, (25 to 30 tons per acre.—Wray), yielding 70 to 80 per cent. of juice, in which are contained 20 per cent. of sugar. The acre of land, therefore, produces, in the house of the sugar-cane, 40 to 50 cwt. of sugar, while the pressed residue furnishes nearly the whole, or the whole, of the fuel necessary for the extraction of the sugar.

For equal periods of vegetation, and equal surfaces, the absolute yield of sugar from the soil in the case of the sugar-cane is more than twice as great as in the case of the beet-root.

The makers of beet-root are in advance of the colonists in having better processes, that is, in saving labour; they have a climate better adapted to the working up of the juice; and they have, perhaps, in general more intelligence. But that the manufacture of beet-root sugar continues among us at all, is owing to accidental circumstances, the duration of which is quite uncertain. The planters of the colonies are already infinitely better informed than formerly; an entire revolution in their methods has begun; they will cease to be negligent and wasteful. It is quite inconceivable that they should continue as hitherto, out of the 20 per cent. of sugar in the cane juices, to lose 12 and to gain only 8 per cent. The discovery of a simple means of preventing the fermentation of the juice in hot climates, and, as a consequence, an increased return of sugar, even to the extent of only 4 per cent., would suffice to render the manufacture of beet-root sugar in Europe impossible, economically speaking. It is for this reason that the latter has no future to look to.

Money no longer makes the wealth of a nation, and if the valley of the Rhine possessed mines of diamonds as rich as those of Golconda, Visiapoor, or the Brazils, they would probably not be worth the working: at those places the cost of extraction is 28*s.* to 30*s.* the carat. With us it amounts to three or four times as much—to more, in fact, than diamonds are worth in the market. The sand of the Rhine contains gold; its proportion of gold, however, being ten times less than that of the gold sands in Siberia, and thirty-seven times less than that of the gold sands of Chili (Daubrée); and in the Grand Duchy of Baden many persons are occupied in gold-washing when wages are low; but as soon as they rise, this employment ceases. The manufacture of sugar from beet-root, in like manner, offers advantages which will soon exist no longer: instead, therefore, of maintaining it at a great sacrifice, it would be more reasonable, more in accordance with true natural economy, to cultivate other and more valuable productions, and with them purchase sugar. Not only would the state be a gainer, but every member of the community. This argument does not apply, perhaps, to France and Bohemia, where the prices of fuel and of colonial sugar are very different from those in Germany.

The manufacture of gas for lighting, from coals, resin, and oils, stands with us on the same barren ground.

The price of the materials from which gas is manufactured in England bears a direct proportion to the price of corn: tallow and oil are only other forms of food for cattle and rent. There the cost of tallow and oil is twice as great as in Germany, but iron and coal are two-thirds cheaper; and even in England the manufacture of gas is only advantageous when the other products of the distillation of coal, the coke, &c., can be sold.

It would certainly be esteemed one of the greatest discoveries of the age if any one could succeed in condensing coal gas into a white, dry, solid, odourless substance, portable, and capable of being placed upon a candlestick, or burned in a lamp. Wax, tallow, and oil, are combustible gases in a solid or fluid form, which offer many advantages for lighting, not possessed by gas: they furnish, in well-constructed lamps, as much light; their combustion is always preceded by their conversion into gas, without requiring the expensive apparatus necessary for the production of coal-gas, and they are generally more economical. In large towns, or such establishments as hotels, where coke is in demand, and where losses in stolen tallow or oil must be considered, together with the labour of snuffing candles and cleaning lamps, the higher price of gas with us is compensated. But even then a great part of the profit depends on the sale of the coke. Where the coke cannot be sold, loss is to be expected. In places where gas can be manufactured from resin, oil of turpentine, and other cheap oils, as at Frankfort, this is advantageous so long as it is pursued on a small scale only. If large towns were lighted in the same manner, the materials would rise in price: the whole amount at present produced would scarcely suffice for two such towns as Berlin and Munich. But no just calculation can be made from the present prices of turpentine, resin, &c., which are not produced upon any large scale, and the production of which cannot well be made the object of industrial exertion.

In the Electorate of Hesse, gas-light might be most advantageously obtained from the excellent coal of Schmalkalden, and it is precisely there that it is unknown. Instead of converting, as at present, these coals into coke at the mouth of the pits, and throwing away the gaseous products, it would unquestionably be better and more profitable to send the coals to Cassel, there to convert them into coke by ignition in retorts, and to use the gas on the spot for lighting the town.

LETTER XIII.

UNTIL very recently it was supposed that the physical qualities of bodies, *i. e.* hardness, colour, density, transparency, &c., must depend upon the nature of their elements, or upon their composition. No one could imagine to himself one and the same body in two different states, and it was tacitly received as a principle, that two bodies containing the same elements in the same proportion, must of necessity possess the same properties. How could it be possible, otherwise, for the most ingenious philosophers to regard chemical combination as an inter-penetration of the particles of different kinds of matter, and matter as susceptible of infinite division? There never was a greater error. If matter were infinitely divisible in this sense, its particles must be imponderable, and billions of such molecules could not weigh more than an infinitely small one. But even the particles of that imponderable matter, which, striking upon the retina, produce that sensation which, when it has reached the inner consciousness, is recognised as light, are not in a mathematical sense infinitely small.

Inter-penetration of elements in the production of a chemical compound, supposes two distinct bodies, A and B, to occupy one and the same space at the same time. If this were so, different properties could not consist with identity of composition.

That hypothesis, however, has shared the fate of all the views of natural phenomena entertained by the philosophers of past times. It has fallen, like them, without any one taking the trouble to maintain it. The force of truth, dependent upon observation, is irresistible. A great many substances have been discovered amongst organic bodies, composed of the same elements in the same relative proportions, and yet exhibiting physical and chemical properties perfectly distinct one from another. To such substances the term *Isomeric* (from *ισος equal* and *μερος part*) is applied. A great class of bodies, known as the volatile oils, oil of turpentine, essence of lemons, oil of balsam of copaiba, oil of rosemary, oil of juniper, and many others, differing widely from each other in their odour, in their medicinal effects, in their boiling point, in their specific gravity, &c., contain the same elements, carbon and hydrogen, in the same proportions. No one of them contains more of either element than the others do.

How admirably simple does the chemistry of organic nature present itself to us from this point of view! An extraordinary variety of the most remarkable compound bodies is produced with equal weights of two elements! and how wide their dissimilarity! The crystallised part of the oil of roses, the delicious fragrance of which is so well known, a solid at ordinary temperatures, although readily volatile, is a compound body containing exactly the same elements, and in the same proportions, as the gas we employ for lighting our streets; and, in short, the same elements, in the same relative quantities, are found in a dozen other compounds, all differing essentially in their physical and chemical properties.

These remarkable truths, so highly important in their applications, were not received and admitted as sufficiently established, without sufficient proofs. Many examples have long been known where the analysis of two different bodies gave the same composition ; but such cases were isolated observations, homeless in the realms of science : until, at length, examples were discovered of two or more bodies whose absolute identity of composition, with totally distinct properties, could be demonstrated in a more obvious and conclusive manner than by mere analysis ; that is, they can be converted and reconverted into each other without addition and without subtraction.

In cyanuric acid, hydrated cyanic acid, and cyamelide, we have three such isomeric compounds.

Cyanuric acid is crystalline, soluble in water, and capable of forming salts with metallic oxides.

Hydrated cyanic acid is a volatile and highly corrosive fluid, which cannot be brought into contact with water without being instantaneously decomposed.

Cyamelide is a white substance very like porcelain, absolutely insoluble in water.

Now if we place the first,—cyanuric acid,—in a vessel hermetically sealed, and apply a high degree of heat, it is converted by that influence into hydrated cyanic acid ; and, then, if this is kept for some time at the common temperature, it passes into cyamelide, no constituent being separated, nor any body taken up from without. And, again, inversely, cyamelide can be converted into cyanuric acid and hydrated cyanic acid.

We have three other bodies which pass through similar changes, in aldehyde, metaldehyde, and elaldehyde ; and again two, in urea and cyanate of ammonia. Further, 100 parts of aldehyde, hydrated butyric acid, and acetic ether, contain the same elements in the same proportion. Thus one substance may be converted into another without the separation of any of its elements, and without the introduction of any foreign body.

The doctrine that matter is not infinitely divisible, but, on the contrary, consists of atoms incapable of further division, alone furnishes us with a satisfactory explanation of these phenomena. In chemical combinations, the ultimate atoms of bodies do not penetrate each other, they are only arranged side by side in a certain order, and the properties of the compound depend entirely upon this order. If they are made to change their place—their mode of arrangement—by an impulse from without, they combine again in a different manner, and another compound is formed with totally different properties. We may suppose that one atom combines with one atom of another element to form a compound atom, while in other bodies two and two, four and four, eight and eight are united; so that in all such compounds the amount per cent. of the elements is absolutely equal; and yet their physical and chemical properties must be totally different, the constitution of each atom being peculiar, in one body consisting of two, in another of four, in a third of eight, and in a fourth of sixteen simple atoms.

The discovery of these facts immediately led to many most beautiful and interesting results; they furnished us with a satisfactory explanation of observations which were before veiled in mystery,—a key to many of Nature's most curious recesses.

Again; solid bodies, whether simple or compound, are capable of existing in two states, which are known by the terms *amorphous* and *crystalline.*

When matter is passing from a gaseous or liquid state slowly into the crystalline form, an incessant motion is observed, as if the molecules were minute magnets; they are seen to repel each other in one direction, and to attract and cohere together in another, and in the end become arranged into a regular form, which under the same circumstances is always the same for any given kind of matter; that is, crystals are formed. But this does not always happen, when gaseous or liquid matter assumes the solid form.

Time and freedom of motion for the particles of bodies are necessary to the formation of crystals. If we force a fluid or a gas to become suddenly solid, leaving no time for its particles to arrange themselves, and cohere in that direction in which the cohesive attraction is strongest, no crystals will be formed, but the resulting solid will have a different colour, a different degree of hardness and cohesion, and will refract light differently. Thus we have cinnabar as a red and a jet-black substance; sulphur a fixed and brittle body, and soft, semitransparent, and ductile; glass as a milk-white opaque substance, so hard that it strikes fire with steel, and in its ordinary and well-known transparent state, with conchoidal fracture. These dissimilar states and properties of the same body are occasioned in one case by a regular, in the other by an irregular arrangement of its atoms; one is crystalline, the other amorphous.

Applying these facts to natural productions, we have reason to believe that clay-slate, and many kinds of greywacke, are amorphous feld-spar, mica slate, or granite; as transition limestone is amorphous marble, basalt and lava mixtures of amorphous zeolite and augite. Anything that influences the cohesion, must also in a certain degree alter the properties of bodies. Carbonate of lime, if crystallised at ordinary temperatures, possesses the crystalline form, hardness, and refracting power of common calcareous spar; if crystallised at a higher temperature, it has the form and properties of arragonite.

Finally, *Isomorphism*, or the identity of form in many chemical compounds having a different composition, tends to prove that matter consists of atoms, the mere arrangement of which produces all the properties of bodies. Might we not almost inquire whether some of those bodies which we regard as elements may not be merely modifications of the same substance?—whether they are not the same matter in a different state of arrangement?

Iron and manganese, cobalt and nickel, platinum and iridium, occur almost always associated respectively in pairs in the same minerals; they possess, in each pair, many properties in common; and the equivalents or atomic weights of each pair are the same. The atomic weights of chlorine and iodine, added together, and divided by two, give almost exactly that of bromine, which, in its physical and chemical properties, stands between them. In like manner, the mean number between those representing the equivalents of potassium and lithium, is very nearly that of sodium. Phosphorus, which is regarded as an elementary body, is known in two states, and the same is true of cyanogen, which exhibits all the chemical properties of an elementary body, except that we can show it to be a compound.

When phosphorus is kept for a time near its boiling point, air being excluded, it undergoes a true coagulation, and at the same time a change in its most striking properties. In its ordinary state it is colourless, easily fusible, very inflammable, luminous in the dark (when in contact with air), and slowly passes, by oxidation, into a deliquescent acid; but when kept for a time at a temperature between 464° and 482° F., it becomes solid, brownish red, much less easily combustible, and is not changed in moist air. Common phosphorus dissolves in all proportions in bisulphuret of carbon; the altered phosphorus is insoluble in that liquid. The former is very poisonous;

the latter, in the same dose, has no action on the animal system, as has been proved by experiments made on dogs. If under the name of phosphorus we understand the conception of certain properties, it is easy to see that the altered phosphorus would not be entitled to that name ; if it were not that we are able to restore to it all the original properties and destroy the new ones, for at a low red heat the altered phosphorus is reconverted into ordinary phosphorus.

A similar transformation occurs in the case of cyanogen. This compound is, in its more usual form, a gas at ordinary temperature, colourless, easily inflammable, and burning with a peculiar red flame ; it is condensed into a liquid by intense cold. But when cyanogen gas is prepared by heating the bicyanide of mercury, a part of the liberated cyanogen is converted into a dark brown solid body, which is very difficultly combustible, but which, when exposed to a strong red heat, is reconverted into ordinary gaseous cyanogen.

In like manner, liquid chloral becomes, when left to itself at the ordinary temperature, solid, white, and porcelain-like, and may then be reconverted, at a higher temperature, into its original form. Styrole, a colourless, highly volatile liquid, soluble in alcohol and ether, becomes, when heated, solid, transparent like glass, insoluble in alcohol, and very sparingly soluble in ether. Heated more strongly, the latter body, solid styrole, is reconverted into the original liquid.

Phosphorus, in its relation to heat, is perfectly analogous to the bodies just mentioned. Now, what is the cause of these transformations in the properties of this element ? What is the mysterious part played here by heat ? We can explain difference of properties in two compounds of the same composition, by a difference in the arrangements of their atoms ; and this view, in many cases, is unquestionably correct.

But how is it with phosphorus, which we must regard as an elementary body? Is phosphorus, perhaps, really a compound? These remarkable phenomena are as yet obviously unexplained; but they open up to us a world of new ideas.

LETTER XIV.

NEITHER heat, electricity, nor the vital force, are capable of connecting the particles of two dissimilar elements into a group,—of uniting them into a compound;—this, the chemical force alone is able to accomplish.

Everywhere in organic nature, in all combinations which are produced in the living animal or vegetable organisms, we meet with the same laws, we find the same fixed and immutable combining proportions, as in inorganic nature.

The substance of brain, of muscle, the constituents of blood, of milk, of bile, &c., are compound atoms, the formation and duration of which depend upon the affinity which acts between their ultimate particles,—their component elements. It is affinity, and no other power, which causes their aggregation. Separated from the living body, withdrawn from the influence of the vital force,* it is the chemical forces alone which

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* The term "vital force," in the present state of science, does not denote a force, *per se*, as we may suppose the terms electricity or magnetism to do; but it is a collective term, embracing all those causes on which the vital properties depend. In this sense it is as just, and may be used with as much propriety, as the name and idea of the "force of affinity," or "chemical force," which denotes the causes of chemical phenomena; of which we know quite as little as we do of the cause or causes which determine vital phenomena.

determine the conditions of their ulterior existence. Upon these depend, according to their energy and direction, the strength or weakness of the resistance which they oppose to external causes of perturbation, —to forces tending to annihilate the chemical attraction existing between their component elements. But LIGHT, HEAT, the VITAL FORCE, the FORCE OF COHESION, and the FORCE OF GRAVITY, exercise a most decided influence upon the number of the simple atoms which unite to form a compound atom, and upon the manner of their arrangement. They determine the form, the properties, the characteristic qualities of the combinations, precisely because they are able to communicate motion to atoms at rest, and to annihilate motion by resistance.

Light, heat, the vital force, the electric and magnetic forces, the power of gravity, manifest themselves as forces of motion and of resistance, and as such, change the direction, and vary the strength, of the chemical force; they are capable of elevating this force, of diminishing or even of annihilating it.

Mere mechanical motion suffices to impart a definite direction to the cohesive attraction of crystallising substances, and to modify the force of affinity in chemical combinations. We may lower the temperature of water, when completely at rest, far below the freezing-point, without causing it to crystallise. When in this state, the mere touch with a needle's point suffices to convert the whole mass into ice in a moment. In order to form crystals, the smallest particles of bodies must be in a state of motion; they must change their place, or position, to be able to arrange themselves in the direction of their most powerful attraction. Many hot, saturated saline solutions deposit no crystals on cooling, when completely at rest; the smallest particle of dust, or a grain of sand, thrown into the solution suffices to induce crystallisation. The motion once imparted propagates itself. The atom to which motion has just been communicated imparts the same impulse to the next, and in this way the motion spreads throughout all the atoms of the mass.

When we bring metallic mercury into a solution of sulphuret of potassium, its surface becomes immediately covered with black amorphous sulphuret of mercury, and as often as this film is removed from the surface it is renewed. If we place this mixture in a well-closed glass bottle, and attach this bottle to the frame of a saw in a saw-mill, which moves up and down several thousand times in an hour, the black powder becomes converted into the finest red cinnabar, the constitution of which differs from the black sulphuret only by its crystalline character.

The common cast-iron of commerce owes its hardness, brittleness, and crystalline texture to its containing carbon ; pure iron, free from carbon, is but very rarely crystalline. The iron of meteoric stones differs from cast-iron inasmuch as it possesses, with a most decided crystalline texture, the greatest malleability, like a very pure wrought iron. But a bar of wrought iron is tough in breaking, and fibrous, showing no crystalline texture in its fracture. Its smallest particles are intermixed without any order or arrangement ; when it is polished, and its surface moistened with an acid, it does not exhibit the characteristic lines and markings of crystalline iron. But if this bar be exposed for a long time to feeble, but constantly repeated, strokes of a hammer, its atoms will be found to alter their position, and, through the influence of the mechanical motion imparted to them, they will arrange themselves in the direction of their most powerful attraction ; the bar will become crystalline and brittle, like cast iron, the fracture being no longer tough and fibrous, but smooth and shining. This phenomenon is manifested more or less speedily in the iron axles of locomotive engines and travelling carriages, and becomes the cause of accidents which cannot be foreseen.

But it is not only upon the external form and character, and upon the arrangement of homogeneous particles, that mechanical forces have a determining influence, but also upon the manner of arrangement of heterogeneous atoms, that is, upon the existence of chemical combinations. The faintest friction, the slightest blow, causes fulminating mercury and fulminating silver to explode; the mere touch with a feather suffices to decompose the ammoniacal oxide of silver, or the iodide of nitrogen. The mere putting the atoms into motion in these instances alters the direction of the chemical attraction. Owing to the motion imparted, the atoms arrange themselves into new groups. Their elements aggregate anew, forming new products.

Far more frequent and evident still is the influence which heat exercises upon the manifestation of affinity. Inasmuch as it overcomes resistances which oppose themselves to the action of affinity, it promotes and effects the formation of chemical combinations. When heat opposes, as a resisting power, the force of affinity, it alters the direction of attraction,—the arrangement of atoms,—it prevents or annihilates the exercise of the affinity. The attraction which dissimilar atoms have for each other, at lower degrees of heat, or lower temperatures, is different from that which they have at a higher temperature. In the highest conceivable degrees of heat, chemical combinations no longer take place.

When a solution of common culinary salt in water is exposed to a very low temperature, the salt crystallises in fine, large, transparent, and pellucid prisms, which contain 38 per cent. and upwards of water in chemical combination, whilst the crystals of the same salt formed at common temperatures are always anhydrous. Upon the slightest touch, the hydrated crystals lose their transparency, and assume a milky appearance; if placed in the palm of the hand they deliquesce, and are converted into a mass of small cubes of anhydrous common salt. The inconsiderable difference of ten degrees (centigrade) in the temperature causes the particles of this crystallising salt to manifest an affinity for water which they do not possess at a somewhat higher temperature, not even at the freezing point of water. The small difference of 18° F., is, as a resistance to affinity, sufficient to counteract its effects.

When carbonate of lime crystallises from its solution in cold water, its particles arrange themselves into the form of the Iceland or doubly refracting spar; when from hot water, we obtain it in the form of arragonite. Both these minerals, although so diverse in their crystalline forms, so different in hardness, specific gravity, and power of reflecting light, contain, nevertheless, absolutely the same proportional amounts of carbonic acid and of lime.

We see in this instance, that particles of carbonate of lime in becoming solid, under the influence of different temperatures, form themselves into substances physically quite different. And it is even still more remarkable that, if we expose a crystal of arragonite to a feeble red-heat, that is, to a heat of a higher degree than that at which it was formed, a commotion or movement takes place throughout the whole mass of the crystal, and without the slightest alteration occurring in its weight, the entire crystal swells up, presenting the appearance of a cauliflower, and becomes converted into a heap of powder composed of minute crystals, each of which exhibits the rhombohedral form of common calcareous spar.

The interior of a hen's egg undergoes, by the influence of a temperature of 165°, a complete alteration in all its properties. The fluid albumen, which, in its natural state, is nearly colourless, presenting only a very feeble yellow tint, assumes a white appearance like porcelain, and its particles lose entirely their mobility. We see that this most remarkable change takes place without the addition of anything material, and without the withdrawal of any substance whatever. Previous to the application of heat, the particles of the albumen admitted of their being intermixed with water in every proportion—they were soluble; but, in consequence of the motion imparted to them by heat, they have lost this property; their constituent atoms have grouped themselves into a new form; and it is the manner of their atomic arrangement which causes this alteration in the properties of the albumen. The chemical forces which were active between the particles of albumen, constitute the ultimate cause of this new mode of arrangement,—of these new physical properties. In this newly-acquired form they manifest a resistance to disturbing forces, of which they were originally devoid; they oppose the influence of heat, as they were not before capable of doing.

All organic substances exhibit similar phenomena; they all, without exception, are mutable and destructible by the influence of a more or less elevated temperature; the resistance which their atoms,—that is, the forces *active* in them,—oppose to the disturbing causes, being invariably manifested in a new manner of arrangement. From a compound atom, one, two, or three new groups of atoms are formed in such order that a state of equilibrium is invariably restored. The power of resistance to disturbing forces,—that is, chemical force,—is stronger in the newly-formed products than in the original substance, but the sum total of the power of affinity does not increase, it only becomes stronger or more intense in a certain direction.

What we mean by the *direction* of the force will be rendered more intelligible by contemplating the state of a particle of water in the centre of a mass of water, as, for instance, in a filled glass. The particle of water in the centre of the glass is attracted by all the surrounding particles in its immediate vicinity, and it exercises the same degree of attraction towards them, and equally on all sides. The mobility of the particle of water, and the facility of its displacement, depend upon the circumstance that all the attracting forces acting upon it are in a state of equilibrium. The application of the slightest external mechanical force suffices to remove it from its place ; the least difference in the temperature, increasing or diminishing its density, causes a change in the position of the particle. If it were attracted more powerfully from one side than another, it would tend towards the direction of the most powerful attraction ; a certain amount of force would be required to divert it from that direction.

The particles of the water upon the surface are precisely in this state ; they are less mobile than the particles of the inferior layers, or those below the surface ; they are more closely connected with each other, denser, in a more contracted state, as if influenced by external pressure.

With a certain degree of caution, a fine steel needle may be maintained swimming upon the surface of water, whilst, if submerged in the water, it instantly sinks to the bottom. This more powerful cohesion of the particles of water at the surface, arises from the particles attracting and being attracted *only in one direction.* The attracting force from below is not opposed by any attraction from above. To enable a steel needle to fall to the bottom of a vessel of water, the particles on the surface must first give way, must be displaced, but they do not yield thus although the needle presses upon them with a weight from seven to eight times greater than that of an equal volume of water.

The attracting force which maintains the connection of constituents in chemical combination, acts in precisely the same manner. The directions of the attractive force become multiplied with the number of elements,—with the number of atoms united into a group. The force of the attraction diminishes in the same proportion as the number of directions increases.

Two atoms united into a compound can only attract each other in one direction; the entire amount,—the sum total of their attracting force, manifests itself in this single direction. If a second and a third atom be added to the group, part of the force will be required to attract and retain these atoms also. The natural consequence of this is that the attraction of all the atoms for each other becomes weaker, and they, therefore, oppose a less powerful resistance than the first two atoms previously opposed to external causes tending to displace them.

The great and most marked distinction between organic and inorganic bodies lies in the former being combinations of higher or more complex orders. Although organic substances are composed of but three, four, or, at most, five elements, their atoms are, nevertheless, far more complex than those of mineral substances.

For example, a particle of common salt, or of cinnabar, presents a group of not more than two atoms, whilst an atom of sugar contains thirty-six elementary atoms, and the smallest particle of olive-oil consists of several hundred simple atoms.

In the common salt, the affinity or attraction is exerted only in one direction; in the atom of sugar, on the contrary, it is acting in thirty-six different directions. Without adding or withdrawing any element, we may conceive the thirty-six simple atoms, of which the atom of sugar consists, to be arranged in a thousand different ways; with every alteration in the position of any single atom of the thirty-six, the compound atom ceases to be an atom of sugar, since the properties belonging to it change with every alteration in the manner of the arrangement of its constituent atoms.

It is evident that impulses of motion, certain causes tending to disturb the force of affinity, which exercise no decomposing influence upon more simply constituted atoms,—as, for instance, those of inorganic substances,—may, nevertheless, be capable of producing alterations in organic atoms ; that is, in all atoms of a higher order.

It is upon the greater complexity of composition of organic bodies, together with the lesser force with which, consequently, their constituent atoms attract each other, that their easier decomposability depends ; heat, for example, disturbs their composition with much greater facility than it does that of inorganic bodies. The atoms of the former, once put into motion, or by the action of heat being separated to a greater distance from each other, arrange themselves into less complex atoms, in which the force of attraction acts in fewer directions, and in which it is consequently able to oppose a proportionably stronger resistance to the further action of causes of disturbance,—of decomposition.

All minerals, or inorganic compounds, are formed by the free and unfettered action of chemical affinity ; but the mode and manner of their aggregation, the arrangement of their particles, depend upon the cooperation of external and extraneous causes ; these latter causes determine the form and the physical properties of the compound. If, for example, the temperature had been higher or lower, whilst the atoms of a compound substance were combining, they would have arranged themselves into quite different groups.

Precisely in the same manner as heat influences inorganic combinations, heat, light, and, above all, the vital force, are the determining causes of the form and properties of compounds produced in living organisms ; these causes determine the number of atoms and the mode and manner of their arrangement.

We are able to construct a crystal of alum from its elements, namely, sulphur, oxygen, hydrogen, potassium, and aluminum, inasmuch as heat as well as chemical affinity are, within a certain limit, at our free disposal, and thus we can determine the manner of arrangement of the simple and compound elements. But we cannot make an atom of sugar from the elements of sugar, because in their aggregation into the characteristic form of a sugar atom the vital force co-operates, which is not within the reach of our control, as heat, light, the force of gravity, &c., are to a certain extent. But when the elements have once aggregated into organic atoms in the living organisms, they come under the same category with all other chemical compounds ; we are able to guide, in various and manifold directions, the force which is active among these atoms, maintaining them in connection ; we are able to alter this force, to increase or to annihilate it. We may produce atoms of a higher order by combining together two, three, four, or more compound organic atoms ; we can decompose the more complex into less complex compound atoms ; we can produce sugar from wood and from starch, and from sugar we can produce oxalic acid, lactic acid, butyric acid, acetic acid, aldehyde, alcohol, formic acid, &c., although we are altogether incapable of producing any of these compounds by direct combination of their elements.

The vital force has not the slightest influence upon the combination of the simple elements, as such, into chemical compounds. No *element*, by itself, is capable of serving for the nutrition and development of any part of an animal or vegetable organism. All those substances which take a part in the processes of life are inferior groups of simple atoms, which, under the influence of the vital force, combine into atoms of a higher order. The chemical force, under the dominion of heat, determines the form and properties of all the more simple groups of atoms, whilst the vital force determines the form and the properties of the higher order of atoms, that is, of organic atoms.

LETTER XV.

The carbon of all parts and constituents of vegetables, and, through vegetables, of animals, is derived from *carbonic acid ;* all the hydrogen of non-nitrogenised organic bodies (sugar, starch, woody fibre, gum, oils, &c.) is derived from *water ;* and all the nitrogen of nitrogenised organic bodies is obtained from *ammonia.* An atom of carbonic acid is a group of three elementary atoms, of which one is a carbon atom, and two are oxygen atoms. No part of a vegetable or animal organism contains, for one atom of carbon, more than two atoms of another element. The great majority of organic bodies contain, for one atom of carbon, less than two other atoms.

All constituents of organisms are formed of atoms of carbonic acid, more or less modified, or of groups of such modified carbonic acid atoms. These atoms and groups of atoms have been produced, under the influence of solar light, from the carbonic acid absorbed by the roots and leaves of plants. The change is the result of a separation and extrusion of part of the oxygen of the carbonic acid atoms, in the place of which oxygen there is taken up hydrogen, or hydrogen and nitrogen. Viewed in the simplest way, an atom of grape-sugar, for example, may be regarded as an atôm of carbonic acid, in which one oxygen atom has been removed and replaced by one hydrogen atom. The formula of carbonic acid is $C\ O_2$; that of grape-sugar may be written $C\left.\begin{matrix}O\\H\end{matrix}\right\}$; or grape-sugar may be regarded as a multiple of this last formula, $C_{12}\left.\begin{matrix}O_{12}\\H_{12}\end{matrix}\right\}$, or $C_{24}\left.\begin{matrix}O_{24}\\H_{24}\end{matrix}\right\}$, according as we suppose it to be derived from twelve or twenty-four atoms of carbonic acid, $C_{12}\ O_{24}$, or $C_{24}\ O_{48}$, by the replacement of half the oxygen by the same number of atoms of hydrogen, twelve or twenty-four. Cane-sugar ($C_{12}\ H_{11}\ O_{11}$), gum and starch ($C_{12}\ H_{10}\ O_{10}$), and the substance of the woody cells, or woody fibre ($C_{12}\ H_8\ O_8$), may be viewed as groups of twelve atoms of the simplest form of grape-sugar, $C\left.\begin{matrix}H\\O\end{matrix}\right\}$, (or if grape sugar be a group with twelve atoms of carbon, as atoms of grape-sugar,) from which, respectively, one, two, or four atoms of *water* have separated.

Quinine, caffeine, and the organic bases or alkaloids in general, contain, besides carbon and the elements of water (oxygen and hydrogen), a certain proportion also of nitrogen. The most complex organic matters, such as the vegetable *albumen* existing in a dissolved state in vegetable juices, and the vegetable *caseine* deposited in many seeds, contain not only the four elements of the organic bases, but, in addition to them, a fifth element, namely, *sulphur*.*

The acids so widely distributed in vegetables, such as oxalic acid (in *oxalis*, *rumex*, *rheum*, &c.); malic acid (in most unripe fruits); citric acid (in the lemon, lime, orange, &c.), and others, stand to each other,

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* This is exclusive of the small but essential quantities of alkaline and earthy phosphates (phosphorus, oxygen, and metals) always found in these compounds, and apparently indispensable to their existence.—W. G.

and to carbonic acid, in a relation as simple as that between carbonic acid and grape-sugar. By the separation from a group of two carbonic acid atoms of one oxygen atom, oxalic acid (anhydrous) is formed. $2\,C\,O_2 = C_2\,O_4$; and $C_2\,O_4 - O = C_2\,O_3 =$ anhydrous oxalic acid. If, to a group of two atoms of oxalic acid, two atoms of hydrogen be added, and from the whole two atoms of oxygen be removed, malic acid is the result. $2\,C_2\,O_3 = C_4\,O_6$; then $C_4\,O_6 + H_2 = C_4\,H_2\,O_6$; and $C4\,H_2\,O_6 - O_2 = C_4\,H_2\,O_4$ $=$ malic acid. We have every reason to believe that, by a continuance of such changes, sugar, gum, starch, and woody fibre are formed from these acids ; and that they (the acids) are links in a chain exhibiting the gradual conversion of the atom of carbonic acid into sugar and the other more complex organic atoms. Sugar contains, along with carbon, oxygen and hydrogen, exactly in the proportions to form water. The acids above named, contain, besides the elements of water, a certain proportion of oxygen in excess. By the further addition of hydrogen, therefore, with or without the separation of oxygen, all these acids may pass into sugar. In proportion as the new products formed from carbonic acid, deviate more and more in composition from that acid, they acquire new properties. The organic acids still possess the acid character of carbonic acid, but in starch or woody fibre this character is entirely lost. The ultimate particles of oxalic acid, tartaric acid, malic acid, citric acid, and sugar, &c., arrange themselves, being crystallisable, in directions determined by an inorganic force ; but in the formation of starch and of cellulose (the substance forming the woody cells) another cause acts, which opposes cohesion, and alters the direction of their attractions. The more complex organic atoms are no longer bounded by straight lines and flat surfaces, but by curved lines and surfaces. The modern researches in organic chemistry have shed light on the origin and formation of these higher or more complex organic compounds. There has been discovered a whole series of bodies, produced by the union of two more simple organic compounds, yet retaining entirely the chemical character of one of these. This is quite contrary to the laws of combination in inorganic chemistry, according to which, as we have always found, the properties of the constituents disappear, to give place to new properties in the compound.

Formic acid and oil of bitter almonds (hyduret of benzoyle) are well-known compounds. They combine to produce the formobenzoic acid, which in its character as an acid agrees entirely with formic acid, without possessing any of the properties of the oil of bitter almonds. The formic acid has retained, the oil has lost, its chemical character, in the new compound. This, and a host of analogous compounds, although formed of two compound bodies, play the part of one of the more simple constituents; that is, of such as we cannot decompose into still simpler, and again reconstruct at pleasure. In order to distinguish this class of bodies, made up of two compounds, yet retaining the chemical character of one, from other compounds, they have been called coupled or paired compounds; and that constituent whose properties disappear, is called the *copula*. In this sense, formobenzoic acid is a coupled acid, in which the oil of bitter almonds is the copula. It is supposed that all the higher or more complex organic compounds are thus formed; and albumen, caseine, and the organic bases are regarded as coupled compounds, which they certainly are, although we do not yet know, and cannot name, the copulæ belonging to them.

By coupling nitrogenised compounds, such as ammonia and hydrocyanic acid, with non-nitrogenised, and also with other nitrogenised bodies, we produce, artificially, compounds possessing all the properties of the nitrogenised acids and colouring matters occurring in nature. Asparagine, a body formed in asparagus and during the germination of the *leguminosæ* and many other plants, has the composition of malate of ammonia, *minus* the elements of water. Now, we are able, from malic acid and ammonia, to produce, not as yet asparagine, but aspartic acid, a body derived from asparagine. Orcine, which is colourless and crystallised, produces, when oxygen is present, by absorbing ammonia, the splendid red dye, orceine. The admirable researches of Wurtz and of Hofmann have shown that every one of the three atoms of hydrogen in ammonia may be displaced and replaced by compound organic atoms; and that in this way new compounds are formed, in which the ammonia retains perfectly its chemical character, as a base. Ammonia neutralises acids, forming with them salts; the new bodies obtained from it by the replacement of its hydrogen are organic bodies, perfectly analogous in chemical characters, not only to ammonia, but also to nicotine, morphine, and quinine.

Universal experience teaches us, that all organised beings after death suffer a change, in consequence of which their bodies gradually vanish from the surface of the earth. The mightiest tree, after it is cut down, disappears, with the exception, perhaps, of the bark, when exposed to the action of the air for thirty or forty years. Leaves, young twigs, the straw which is added to the soil as manure, juicy fruits, &c., disappear much more quickly. In a still shorter time animal matters lose their cohesion; they are dissipated into the air, leaving only the mineral elements which they had derived from the soil.

This grand natural process, of the dissolution of all compounds formed in living organisms, begins immediately after death, when the manifold causes no longer act, under the influence of which they were produced. The compounds formed in the bodies of animals and of plants undergo, in the air and with the aid of moisture, a series of changes, the last of which are the conversion of their carbon into carbonic acid, of their hydrogen into water, of their nitrogen into ammonia, of their sulphur into sulphuric acid. Thus their elements resume the forms in which they can again serve as food to a new generation of plants and animals. Those elements which had been derived from the atmosphere take the gaseous form and return to the air; those which the earth had yielded, return to the soil. Death, followed by the dissolution of the dead generation, is the source of life for a new one. The same atom of carbon, which as a constituent of a muscular fibre in the heart of a man assists to propel the blood through his frame, was, perhaps, a constituent of the heart of one of his ancestors; and any atom of nitrogen in our brain has, perhaps, been a part of the brain of an Egyptian or of a negro. As the intellect of the men of this generation draws the food required for its development and cultivation from the products of the intellectual activity of former times, so may the constituents or elements of the bodies of a former generation pass into, and become parts of, our own frames.

The proximate cause of the changes which occur in organised bodies after death is the action of the oxygen of the air on many of their constituents. This action only takes place when water, that is, moisture, is present, and requires a certain temperature.

This influence of atmospheric oxygen is very distinctly seen in fruits and other soft parts of vegetables, when, by an injury to their surface, the juice comes into direct contact with the air. When an apple is bruised at one point, a process of decomposition begins from the injured part. A brown spot appears, which increases in a regular concentric circle, till at last the whole apple becomes rotten, or is changed into a brown, soft, viscid mass.

The juice of the grape, while it is protected by the external skin from contact with atmospheric air, scarcely undergoes any perceptible alteration. A grape, by gradual exsiccation, becomes converted into a raisin. The slightest perforation through its external covering, as with the point of a needle, for instance, is sufficient to alter all the properties of the juice.

If we cut an apple, a potato, or a beet-root, the cut surface in the course of a few minutes loses its white colour, and assumes a brown tint.

Animal fluids comport themselves in a precisely similar manner. Milk, whilst in the udder of the cow, urine whilst in the bladder, undergo, in a healthy state, no alteration of their properties. But in contact with air, milk coagulates without any evolution of gas, and becomes acid ; the caseine separates in the form of a curdy mass ; urine, which is acid, becomes alkaline ; and, after a time, when an acid is added, it effervesces from the escape of carbonic acid gas.

In like manner, a process of decomposition sets in, after death, in the bodies of men and animals, which begins in the inside in those parts, such as the lungs, which are in contact with the air. When there are wounds, it spreads from them, and, in diseases, from the diseased part; so that, in many cases, death itself is nothing else than the result of a decomposition going on in an inward part. With the disease, of which it is the proximate cause, this process begins, and it continues after death.

The most remarkable of these phenomena is certainly this, that, in many cases, the change once begun in organic matters, continues when, after transient contact with the air, the atmospheric oxygen is entirely excluded. *Must*, the fermenting grape juice, continues to ferment in closed vessels ; and the fermenting wine, in the manufacture of champagne, often bursts the strongest bottles. Milk, once exposed to the air, coagulates, and becomes sour even in hermetically sealed vessels.

It is obvious that, by the contact of these organic bodies with the oxygen of the air, a process begins, in the course of which their constituents suffer a total change in their properties. This change is a result of a change in their composition. Before contact with the oxygen, their constituents are arranged together, without action on each other. By the oxygen, the state of rest or equilibrium of the attractions which keep the elements together, has been disturbed in a particle of the substance, and, as a consequence of this disturbance, a separation or new arrangement of the elements has been brought about.

The continuance of these processes, even when the oxygen, the original exciting cause of them, no longer acts, shows most clearly, that the state of decomposition, which has been produced among the elements of a particle of the mass, exercises an influence on the other particles, which have not been in contact with the oxygen of the air; for not only the first particle, but, by degrees, all the rest, undergo *the same change*.

All those processes of decomposition which begin in a part of an organic substance from the application of an external cause, and which spread through the whole mass, with or without the co-operation of that cause, have been called processes of *Putrefaction*. A putrescible substance, therefore, is distinguished from one not putrescible, because the former, without other conditions than a certain temperature, and the presence of water, (after exposure, although transient, to the atmosphere,) are resolved into a series of new products; while the latter, if unmixed, do not, under the same circumstances, undergo any change.

The number of substances occurring in nature, which, according to this definition, are truly putrescible, is singularly small; but they are everywhere diffused, and form part of every organised being. Before all other substances, this property of putrescibility belongs to the highly complex matters of the animal and vegetable kingdoms, which contain nitrogen and sulphur; such as albumen, fibrine, caseine, gelatine, and the like.

Urea, sugar, sugar of milk, asparagine, and amygdaline, as well as the various organic acids, undergo, when pure, under the circumstances above mentioned, (the presence of air and water, with a certain temperature,) no perceptible change. Solution of sugar, and sugar of milk, or of urea, when exposed to a gentle heat, dry up; the dissolved matters separate in crystals, without losing any of their properties.

The examination of vegetable juices, and of animal fluids, such as milk and bile, of grape juice and of urine, &c., shows that they contain two kinds of substances, of entirely different nature and composition; one which is putrescible, and along with it, another, or several, which, by themselves are utterly unsusceptible of that spontaneous change. Now, when these fluids, left to themselves, enter into decomposition, we observe the remarkable phenomenon, that both kinds of bodies, the putrescible as well as those which, by themselves, are imputrescible, disappear simultaneously, being resolved into new products. But the latter bodies, without the presence of the former, would have remained unchanged.

If we cause a putrescible body, such as caseine, fibrine, blood, or animal mucus, to enter into putrefaction, and then add to it a solution of sugar, or of sugar of milk, or of urea, &c., these substances pass into fermentation; that is, into decomposition.

It is obvious, from these facts, that putrescible matters, in the state of putrefaction, when brought into contact with a large number of non-nitrogenised as well as nitrogenised substances, of themselves not putrescible, effect a change of composition in them. It will now be easy to understand the distinction between putrefaction and fermentation.

All non-putrescible bodies are called fermentescible, when they possess the property of being decomposed by contact with putrescent matters. The process of their decomposition is now called fermentation. The putrescent body, by which this change is caused, is now named the Ferment.

All putrescible substances, in the state of putrescence, become ferments ; that is, they acquire in this state the power of causing some one or more of the fermentescible substances to enter into fermentation ; and the putrescent body or ferment retains this power, until its fermentation is completed.

The changes which fermenting bodies undergo, depend on the resolution of a very complex atom into two or more less complex atoms. The 36 elementary atoms in an atom of crystallised sugar, $C_{12} H_{12} O_{12}$, are resolved into 4 atoms of carbonic acid, $4 CO_2$, containing 12, and 2 atoms of alcohol, $2C_4 H_6 O_2$, containing 24 simple atoms. The sugar of milk contained in fresh milk (also $C_{12} H_{12} O_{12}$) resolves itself into two atoms of lactic acid, $2 C_6 H_6 O_6$, containing the same number of elementary atoms as the sugar of milk.

Since no foreign element has been added to the sugar of milk, when it was changed to lactic acid, and none of its elementary atoms have been separated or expelled, it is quite certain that the change of properties depends on a change in the position or place of the atoms of the sugar of milk, and that these are arranged in a new order in the lactic acid. By the cause which effected the change, it is obvious that the atoms of the sugar of milk must have been set in motion ; for in order to arrange themselves in a new order, they must move.

Putrescent bodies exert an action on complex organisations, which, by themselves, are not putrescible; it is certain that their action depends on a certain state in which their atoms are; it is further certain, that this state is one of change of place, or a resolution into simpler atoms of the complex atoms of the putrescent body; and it is equally undeniable, that by their contact with fermentescible bodies, the elements of the latter also assume new positions; whence it follows, that the atoms of fermentescible bodies, in contact with putrescent matters, behave as if they formed part of the putrescent substance. The atoms of the fermentescible body (sugar, &c.) participate in the motion of the atoms of the ferment; the change of position or state of motion in the ferment causes the atoms of carbon, hydrogen, and oxygen of the fermentescible body also to change their position or place.

Hence we can see why these processes have a beginning, a certain duration, and an end, in which respects they are distinguished from ordinary cases of chemical action. When we add sulphuric acid to a salt of baryta, decomposition instantly takes place at all points where the acid comes in contact with the baryta. The beginning is at the same time the end, and the elements of the sulphate of baryta, when formed, have no further action.

But a putrefying body goes through a whole series of changes, and in every stage it exerts a peculiar action. When a change has been effected in the position or arrangement of the atoms of sugar in grape juice, or in infusion of malt, no further change takes place with regard to these atoms; but the change in the altered substance (a compound containing nitrogen and sulphur), which has acted as a ferment and has separated as yeast, continues to go on. If the yeast be taken out of the fermented liquor, and added to a solution of sugar, a number of sugar atoms undergo the former change, as in the grape juice or malt infusion; and the yeast or ferment retains this power, until it has gone through the entire series of changes belonging to its putrefaction, until the separation and new arrangement of its atoms are complete, and a state of rest or equilibrium is attained. If, after this point, sugar be still present, its atoms remain unchanged. According to the amount of ferment present, the time required for the fermentation is determined. By doubling or tripling the proportion of ferment, the time is shortened, or a larger quantity of the sugar or other fermentescible body is decomposed.

If we divide a vessel containing solution of sugar into two cells by a partition of filtering paper, which allows the dissolved sugar to pass through, but not the globules of the yeast, and if we add yeast to the solution in one cell, fermentation occurs in that cell only; that is, where sugar atoms and yeast atoms come into contact, there alone the resolution of sugar into alcohol and carbonic acid takes place.

The action of ferments on fermentescible bodies is analogous to that of heat on organic substances. Their decomposition at high temperatures is always the result of a change in the position of their atoms. Heat causes an expansion, or increase of volume; at first it affects the adhesion of the atoms as grouped; and at a higher temperature the atoms constituting the groups separate from each other. Heat disturbs the equilibrium of attractions among the atoms; the liquid and gaseous states are new states of equilibrium between the effects of heat and those of cohesion, as applied to the groups of atoms. When, at a high temperature, the complex atoms or groups constituting organic matters are decomposed, they always yield products which are permanent and unchangeable at that temperature, but which are destructible by a higher one. Every fixed degree of heat corresponds to a peculiar state of equilibrium between heat and the chemical attraction which keeps together the elements of organic atoms.

We cannot render a piece of sugar liquid, let us grind it never so finely; and still less can we decompose an atom of sugar by mechanical force, or detach from it an atom of carbon or hydrogen. We can, by shaking a solution of sugar, cause the particles of sugar and those of water to move on one another; but their elements do not, in this case, change their relative position.

In putrefaction and fermentation, it is not the groups of atoms, but the atoms in the groups, which change their place; and it is this internal motion, in putrescent bodies, which causes change of place in the atoms of the fermentescible body; that is, when the chemical force which holds their elements together, is less than the force which tends to separate them.

The influence of temperature on the nature of the products of fermentation is truly remarkable. The juice of carrots, beet-root, or onions, which is rich in sugar, when allowed to ferment at ordinary temperature, yields the same products as grape juice. But, at a higher temperature, the whole decomposition is changed. There is observed a much less copious evolution of gas, and no alcohol is formed. If we examine the fermented liquid, there is no longer in it any sugar. But a large quantity of lactic acid, and a body resembling gum arabic; and, as the most remarkable product, a crystallisable substance, in composition and properties identical with the chief constituent of manna, namely mannite;—all these are found to have been produced.

Alcohol and carbonic acid are the products of the decomposition of sugar by fermentation at the ordinary temperature; carbonic acid, mannite, lactic acid, and gum, are the products of its fermentation at a higher temperature. The kind of fermentation of milk-sugar in milk, when it passes into lactic acid, chiefly occurs at ordinary temperatures. At a heat of from 76° to 90°, the caseine acquires the properties of common yeast, and there occur, in the milk sugar, at these higher temperatures, two successive transformations. It first passes into grape sugar, by taking up the elements of water, and then, by contact with the caseine or cheese (the ferment), it is resolved into alcohol and carbonic acid.

At the ordinary temperature, milk ferments without evolution of gas, and lactic acid is formed. At higher temperatures we obtain, as the result of the altered fermentative process, an alcoholic liquid, which by distillation yields true spirits.

It is obvious that only those bodies are fermentescible in which the elements are mobile, and only held together by a feeble attraction ; and if, in fact, by the change of place, or motion, in the elements of the ferment, a similar change, or motion, has been induced in the particles of another body in contact with them, it is certain that the atoms of the latter opposed to the motion acting on them a resistance, which had to be overcome, before they could be set in motion. This resistance, how feeble soever we may suppose it, acts like a force, which must re-act on the atoms of the ferment, whereby the change or motion among them must be altered in its character. A putrescent body, therefore, in contact with a fermentescible one, which it causes to enter into fermentation, must yield products different from those obtained when it putrefies alone. We observe, in fact, that, when solution of sugar is added to putrescent animal cheese, or blood, the beginning of the fermentation is attended by the diminution of the formation of those products which give their offensive smell to putrid animal matters ; so that, in the course of the process, these striking products entirely disappear. It is further plain, that a fermentescible body must cease to be fermentescible when the resistance opposed to the action of the ferment on its atoms, or the force which holds the atoms in groups, is increased. There are indeed many bodies which oppose putrefaction and fermentation, and which impede or arrest the course of these processes ; and this remarkable action frequently depends on their forming a chemical compound with the ferment. By the addition of a body having affinity to the ferment, the tendency of its particles to retain their original arrangement is obviously strengthened ; for, in addition to the force which holds them in groups, we have in the new body, which combines with the ferment, a new attraction, which must be overcome before the atoms of groups of the ferment can change their position.

To the list of bodies which check putrefaction and fermentation, or antiseptics, belong all substances which exert a chemical action on ferments ; such as alkalies, mineral acids, concentrated vegetable acids, volatile oils, alcohol, sea salt. The most effective are sulphurous acid, metallic salts, especially those of mercury, which combine chemically with the ferments or putrescent bodies. Arsenious acid does not prevent the putrefaction of the blood, nor the ordinary alcoholic fermentation of sugar ; but the putrefaction of the skin and of the gelatinous tissues is entirely suppressed by the presence of arsenious acid.

Many organic acids, in the form of their lime salts, are fermentescible, although not so by themselves. Malate of lime ferments with yeast, as readily as solution of sugar. At a low temperature pure carbonic acid gas is evolved, and the malate is resolved into succinate, acetate, and carbonate of lime. At a higher temperature, hydrogen gas is evolved, and there is produced, from the malic acid, a large quantity of butyrate of lime.

Lactate of lime yields, in contact with putrid cheese, carbonic acid and hydrogen gases, butyric acid, and mannite. Tartrate of lime yields carbonic acid, metacetonate, and acetate of lime.

By the neutralisation of these acids with lime, their chemical action on the ferment is prevented as they are formed ; and the liquid remains neutral during the process, because the lime set free by the formation of organic acids of a higher order, and of a less capacity of saturation, is deposited in the form of insoluble carbonate.

The ferments present in grape juice and other vegetable juices, are, without exception, such bodies as have the same composition as blood or cheese. The production of these blood-constituents in plants, in the vine for example, may be increased and exalted by animal manure. Cow-dung and urine being rich in carbonated alkalies, exerts its influence chiefly on the amount of sugar, that is, of the fermentescible body. Human excrements, on the other hand, contain only phosphates, and act most powerfully on the production of the blood-constituents (or albuminous matters), that is, of the ferments, in plants.

It is easy to see, that by careful cultivation, by a proper choice of manures, we can affect most decidedly the quality of the juice (for example, of the grape). When the grape juice, or *must*, is rich in albuminous ferments, we act rationally in adding sugar to it, although that sugar may have been formed in another plant, or when we add to the juice of the unripe grapes of our climate, the ripe dried raisins of a more southern one. Scientifically speaking, these additions are true improvements, which in no sense can be regarded as deceptive adulterations.

Changes in the nature of the products occur in every kind of fermentation, caused partly by changes of temperature, partly by the presence of other bodies than the chief fermentescible one, which are drawn, as it were, into the process of transformation. Thus we obtain from the same grape juices, when fermented in different temperatures, wines of different quality and character; for, according as the temperature of the air in the harvest season is high or low, according to the depth of the fermenting cellar and its temperature during the fermentation, the quality, the smell, and the taste of the wine varies. A constant temperature in the fermenting cellar, and a fermentation, not tumultuous, but gradual and steady, are the most favourable conditions within our power to realise, for producing a noble or first growth wine. It will not be long before the wine-growers employ in the manufacture of wine the deep rocky caves which are found so advantageous for the making of the finer sorts of beer, in preference to all other cellars; and the advantage of these caves depends chiefly on their constant temperature.

The influence which extraneous substances exercise upon the products of vinous fermentation is strikingly exemplified in the fermentation of potato-mash. It is well known that in the manufacture of potato-spirit an oily liquid is obtained, besides the alcohol, possessing poisonous properties, a highly disagreeable smell, and nauseous taste; this is called *oil of potato-spirit*, or *fusel oil.* It does not exist ready formed in the potato, but is a product of the transformation of sugar; for it is produced not only in the fermented potato-mash, but also in the fermentation of the last syrups obtained during the preparation of the beetroot sugar.

This fusel oil belongs, by its chemical properties, to the same class of bodies as alcohol; it is an alcohol from which the elements of water have been separated. Two atoms of fusel oil are formed by the aggregation of five atoms of alcohol, with the separation of six atoms of water.

Fusel oil is produced in our spirit manufactories, as an accidental and accessory product, in such large quantities that it is used for lighting the buildings. Its formation never takes place in fermenting fluids containing racemic acid, tartaric acid, tartar, or bitartrate of potash, or citric acid, or certain bitter substances, such as hops, or the extract or volatile oil of hops.

Fusel oil is formed principally in alkaline or neutral fluids, and in such as contain lactic acid or acetic acid, and its production in the potato-mash may be prevented, in a great measure, by the addition of tartar to the fermenting fluid.

The odour and flavour of wines depend invariably upon certain combinations which are formed during fermentation. Old Rhine wines contain acetic ether, many of them a very minute proportion of butyric ether, which impart to them a peculiar and agreeable smell and taste, somewhat resembling old Jamaica rum. All wines contain œnanthic ether, upon the presence of which depends their vinous odour.

These various compounds are formed partly in the process of fermentation and partly while the wine is in the cask, by the action of acids, which are present, upon the alcohol of the wine. Œnanthic acid seems to be produced by fermentation; at least it has not been detected in the grape. The free acids which are present in the fermenting juice take a most decided part in the formation of those aromatic matters upon which odour and flavour depend. The wines of southern regions are produced from perfectly ripe grapes; they contain tartar, but no free organic acids; they scarcely possess the characteristic odour of wine, and with respect to bouquet or flavour they cannot bear a comparison with the nobler French or Rhenish wines.

LETTER XVI.

THE properties of common animal caseine (cheese), and the influence which its particles, when in a state of decomposition and transposition, exercise upon the particles of sugar in contact with them, are very remarkable and interesting; but far more extraordinary, and of surpassing interest, are the properties and action of vegetable caseine, as it is contained in the milk of almonds. It is universally known that when sweet almonds are reduced to a pulpy mass, mixed and rubbed down with from four to six times their weight of water, they yield a fluid, exhibiting, in its external appearance and properties, the greatest analogy to very rich cow's milk. The milky appearance of almond emulsion is caused by particles of oil, or fat in a state of minute mechanical division, being diffused through it, and these rise to the surface when this fluid is left at rest, and arrange themselves in the form of cream, just as is the case with the milk of the cow. Almond-milk, like animal milk, coagulates upon the addition of vinegar, and after a certain time, if left to itself, it turns sour. This milk contains a substance exactly analogous, in its properties, to animal caseine or cheese, and of the same ready mutability. The cheese of animal milk begins to undergo alteration from the instant it leaves the udder of the cow, and the change proceeds in it continuously, although it only becomes perceptible after the lapse of some time in the coagulation of the milk. In a manner precisely similar, transformation takes place in the elements of vegetable caseine, from the very moment that sweet almonds are converted into almond-milk. The vegetable caseine of the almond, like animal caseine, contains sulphur, but it contains a larger proportion of nitrogen than the latter substance. The circumstance that animal caseine does not produce the same effect as a ferment in all cases is, perhaps, to be ascribed to its inferior amount of nitrogen.

With respect to their influence upon the fermentation of sugar, the properties of animal and vegetable caseine are identical. If to a solution of grape-sugar (which is the same in composition as starch-sugar and the solid part of honey) milk of almonds, or pounded almonds freed by means of *cold pressure* from their mixed or fatty oil, be added, and the mixture be kept in a warm place, it will soon run into a lively vinous fermentation, and a brandy of a peculiar, but highly agreeable, flavour, may be obtained by distillation from the fermented fluid.

Animal caseine also produces the same effect ; but the vegetable caseine of almond-milk causes decompositions and transformations in a number of organic compounds, such, for instance, as salicine and amygdaline, which animal caseine does not produce.

Salicine is that constituent of the bark of the willow which imparts to it its well-known intensely bitter taste, and the property of assuming a carmine-red tint when moistened with a few drops of concentrated sulphuric acid. Salicine may be very easily extracted from willow-bark by means of water. In its pure state it presents the form of white, shining, long, needle-like crystals, interwoven with each other like a silken web. Salicine, like sugar, is devoid of nitrogen.

If salicine is placed in almond milk, its bitter taste soon disappears, and is replaced by a purely sweet flavour. At this juncture all the salicine has vanished, and we have grape-sugar in its place, together with a new substance totally different to salicine, namely, *saligenine.*

Sugar and saligenine, together, contain the elements of salicine. An atom of salicine, upon coming into contact with the caseine of almond-milk, is resolved into one sugar atom and one saligenine atom, without the addition or withdrawal of any element whatever.

The deportment of this vegetable caseine toward amygdaline is even still more remarkable. The peculiar products which are obtained from bitter almonds were, for a long time, considered to be a problem, nearly, if not altogether, inexplicable, until amygdaline was discovered to be a constituent of bitter almonds, and the changes it undergoes from the influence of vegetable caseine were brought to light.

If bitter almonds are finely powdered, mixed with water, and submitted to distillation, an aqueous fluid is obtained, with a strong odour, exhibiting a milky appearance from a number of small oil-globules being suspended in the fluid ; these globules of oil coalesce, subside, and form a stratum of oil at the bottom of the vessel. This oil is, therefore, heavier than water; it is also volatile, and has a powerful smell and taste of bitter almonds : moreover, it is characterised by the property of solidifying, when exposed to the air, with the absorption of oxygen, into inodorous crystals of benzoic acid. Besides this volatile oil,—which is an article of commerce to a considerable amount, being used in perfumery,—the water passing over contains also a considerable proportion of *hydrocyanic acid.* Neither of these two products of the distillation of bitter almonds with water, namely, hydrocyanic acid and oil of bitter almonds, can be detected by any means in the bitter almond itself. Were they contained in the bitter almond, as oil of turpentine exists in the resin of the pine, or oil of roses in the rosepetals, we might, of course, feel assured that they would admit of being extracted from the almonds by means of fatty or fixed oils, or other solvents. But the fat oil, which is easily obtained from bitter almonds by pressure, is as bland and insipid as that expressed from sweet almonds; not the slightest trace of hydrocyanic acid, nor of the volatile oil of bitter almonds, can be detected in it, although both substances are readily soluble in it. If bitter almonds are boiled with alcohol, not a trace, either of hydrocyanic acid, or of the volatile oil of bitter almonds, is found in the alcohol; but, upon evaporation, a white crystalline substance is obtained, of easy solubility in water, which imparts to its solution a slightly bitter taste. This substance differs materially from sugar and salicine by invariably containing a small amount of *nitrogen*. It is termed AMYGDALINE. The discoverer of this substance concluded that the hydrocyanic acid and volatile oil of bitter almonds are formed from it, or that the elements, the combination of which furnish those two bodies, must have aggregated, through the action of alcohol, to form amygdaline. Not finding any key to this enigma, he (as is but too frequently done) ascribed the formation of amygdaline, or the transformation of its elements into hydrocyanic acid and oil of bitter almonds, to the cooperation of an intangible and invisible something, which, from its nature, must be beyond the reach of our understanding.

All these phenomena admit of a very simple explanation. We now know that upon bringing a solution of amygdaline and water into fresh almond-milk, decomposition takes place in the course of a few seconds, and the amygdaline atom, in consequence of a new mode of molecular arrangement, resolves itself into hydrocyanic acid, volatile oil of bitter almonds, and sugar, the atoms of which, ninety in number, were, with the exception of four atoms of water, which have been taken up, aggregated into one group in the amygdaline atom ; that is, the amygdaline is constituted of the elements of all these substances combined into a single group or atom.

The quantity of amygdaline which, under these circumstances, is, through the agency of vegetable caseine, separated into those different compounds, depends, in a certain measure, upon the amount of water present in the mixture. Whether the water is sufficient to dissolve all the new-formed products, or insufficient for that purpose, determines whether all the amygdaline or only a part of it becomes decomposed. The volatile oil of bitter almonds requires thirty parts of water for its solution, the other products require less. If, therefore, only so much amygdaline is added to the almond-milk that to thirty parts of water no more than one part of oil of bitter almonds could be formed from it, the whole of the amygdaline disappears ; if more amygdaline than this proportion is added to the mixture, the amygdaline added in excess undergoes no alteration. It is very evident that the chemical affinity of the water, that is, its solvent power, plays a part in this process of transformation ; its affinity or attraction for one of the products co-operates as a cause of decomposition.

Now, since the white constituent of bitter almonds is absolutely identical with the vegetable caseine of sweet almonds, it may easily be conceived that the amount of amygdaline existing, as such, in almonds, depends solely upon the greater or lesser amount of moisture contained in them—a part of the amygdaline, proportionate to the amount of water present, exists in the almond only in its products. A quantity of amygdaline, corresponding to the small amount of moisture in the almonds is only to be traced in the form of the products of its transformation ; hence the smell and taste of the bitter almonds ; but when the almonds are finely powdered and mixed up with a large amount of water—when they are converted, for instance, into almond milk,—the amount of amygdaline decreases with the increasing proportion of water added, until, at last, upon the further addition of water, it altogether disappears.

The deportment of amygdaline, with the white caseous constituent of almonds, assumes a still higher degree of interest when we consider that the presence of amygdaline in the almonds depends upon the accidental position of the tree upon which they grow. Botanists can find no perceptible difference between two trees, one of which bears sweet, the other bitter almonds. Instances are known of trees bearing bitter almonds which, by simple transplantation, were made to produce sweet almonds ; and this is certainly one of the most interesting examples of the influence which certain constituents of the soil exercise upon the vital processes of plants.

The effect of the presence of water upon the existence of certain organic combinations is abundantly evident from the foregoing facts ; there are, however, other instances which may be adduced in illustration, so highly interesting in themselves, that we cannot avoid introducing them in connection with this subject.

It is well known to every one that mustard-seed, powdered, and formed into a paste with water, yields in the course of a few minutes a mixture which, placed upon the skin, produces excessive irritation, so much so as even to raise blisters. This action is caused by a volatile oil containing sulphur, but free from oxygen. This oil may be obtained from mustard by distillation with water, in the same manner as the oil of bitter almonds is obtained from bitter almonds. It is to this volatile oil that the mustard eaten at table owes its smell and taste. In its purest state it is frightfully acrid and pungent. Now, in the mustard-seed there exists no trace of this oil ; the fixed oil expressed from mustard-seeds is bland and destitute of any pungency. The volatile oil is formed from a substance rich in sulphur and nitrogen, and possessing itself no pungency. This substance, by the action of the vegetable caseine contained in the mustard-seeds, undergoes decomposition immediately upon the addition of a sufficient amount of water, and the volatile pungent oil is one of the new products originating from the transposition of its elements.

As vegetable caseine, in the seeds of mustard and in almonds, exercises a decomposing influence upon the other constituents of the same seeds, in consequence of the state of transformation into which it passes immediately upon coming into contact with water, so also the similarly constituted sulphur and nitrogen compounds of nearly all seeds comport themselves, and especially that contained in the grain of the cereals, well known under the term *gluten.*

The flower of wheat, rye, or any of the cereals, when mixed with twenty times its amount of water at 75° C., = 167° F., yields a thick paste, which, after the lapse of a few hours, becomes thin and fluid, and assumes a very sweet taste. The starch of the flour absorbs a certain amount of water, and, in consequence of a new manner of arrangement of its atoms, changes first into a kind of gum, and then into grape-sugar. This transformation is caused by the gluten of the flour passing itself into a state of decomposition. The liquefaction of the dough in the preparation of bread depends upon the same cause.

The same formation of sugar takes place in the germination of corn. All the starch contained in wheat, barley, rye, &c., becomes, during the development of the germ, converted into sugar by the action of the adjacent particles of gluten. The gluten itself assumes quite altered properties; it becomes soluble in water, like starch.

If the aqueous extract of germinated corn (malt), prepared in the brewing of beer, which is called sweet-worts, is heated to the boiling point, a quantity of the gluten which had become soluble and dissolved in it, separates in a state in which it cannot be distinguished from coagulated animal albumen. The remaining portion of the gluten is contained in the worts, in the same state of solution as the matter in the juice of the grape; and when it is boiled with hops, concentrated by evaporation, and mixed with beer yeast, there is obtained, after fermentation, beer; while the dissolved gluten separates as beer yeast, in a quantity 20 to 30 times greater than that of the yeast added to the worts.

In living organisms we observe, on the great scale, phenomena of a similar kind, dependent upon identically the same, or, at least, closely analogous causes. Many plants with woody stems are found to contain in autumn a matter perfectly like the starch of potatoes, or of the cereals, deposited in the substance of the wood, which in the spring, when the plants reawaken to life, becomes converted into sugar. The ascending juice of the maple is so rich in sugar that in regions where this tree occurs in such numbers as to form forests, its juice is employed in the manufacture of sugar. We have every reason to believe that this sugar is formed by a transformation of starch, in a precisely similar manner as the sugar of germinating seeds.

The maturation, as it is called, or sweetening of winter fruits, when stored up for their preservation in straw, is the result of a true fermentation. Unripe apples and pears contain a considerable amount of starch, which becomes converted into sugar by the nitrogenous constituent of the juice passing into a state of decomposition, and transmitting its own mutations to the particles of starch in contact with it.

Redtenbacher has recently found formic acid to be a product of the fermentation of the leaves and twigs of pines. This discovery is the more interesting, as it will probably enable us to explain the presence of this acid in *ants*, especially in those species of these animals which, for their nourishment, partake only of substances in which no formic acid can be found.

The skin of animals, the mucous membrane of the stomach and intestines, and the urinary bladder, have many properties in common with *gluten* and *yeast*. In their fresh state these substances exercise not the slightest influence upon starch or milk-sugar, but when placed in water for a few hours, or even when simply exposed to the atmosphere, they quickly pass into a state of decomposition, which renders them capable of converting with great rapidity starch into sugar, and milk-sugar into lactic acid.

This property of the mucous membrane of the stomach of the calf has been made use of from time immemorial, in the preparation of cheese, in order to make milk coagulate, or, in other words, to effect a separation of the cheese from the other constituents of milk.

The solubility of cheese in milk is in consequence of the presence of alkaline phosphates and of free alkalies. In fresh milk these substances may be easily detected by the property it possesses of restoring the blue colour to reddened litmus-paper. The addition of any acid, by neutralising the alkali, causes the cheese to separate in its naturally insoluble state. The acid indispensable for the coagulation of milk is not added to the milk in the preparation of cheese, but it is formed in the milk at the expense of the milk-sugar present. A small quantity of water is left in contact with a small piece of a calf's stomach for a few hours or for a night;—the water absorbs a quantity of the decomposed mucous membrane so minute as to be scarcely ponderable; this, called *rennet*, is mixed with milk; its state of transformation is communicated (and this is here the most important circumstance) not to the cheese, but to the milk-sugar, the elements of which transpose themselves into lactic acid, which neutralises the alkali, and thus causes the separation of the cheese. By means of litmus-paper the process may be followed and observed through all its stages; the alkaline reaction of the milk ceases as soon as the coagulation begins. If the cheese be not immediately separated from the whey, the formation of lactic acid continues, the fluid turns acid, and the cheese itself passes into a state of decomposition.

Fresh cheese-curd, carefully freed from water and milk-sugar, by expression, and the addition of salt, is a mixture of caseine and butter; it contains all the phosphate of lime, and part of the phosphate of soda, of the milk. When kept in a cool place, a series of transformations takes place, in consequence of which it assumes entirely new properties; it gradually becomes semi-transparent, and more or less soft throughout the whole mass; it exhibits a feebly acid re-action, and developes the characteristic caseous odour. Fresh cheese is very sparingly soluble in water, but after having been left to itself for two or three years it becomes—especially if all the fat be previously removed—almost completely soluble in cold water, forming with it a solution, which, like milk, is coagulated by the addition of acetic acid or the mineral acids. The cheese which, while fresh, is insoluble, returns during the maturation, or ripening, as it is called, to a state similar to that in which it originally existed in the milk. In those English, Dutch, and Swiss cheeses which are nearly inodorous, and in the superior kinds of French cheese, the caseine of the milk is present in its unaltered state. The odour and flavour of cheese is owing to the decomposition of the butter; the non-volatile acids, margaric acid and oleic acid, and the volatile butyric acid, capric and caproic acids, are liberated in consequence of the decomposition of glycerine (the sweet principle of oils, or, as it might be termed, the sugar of oil). The volatile acids impart to cheese only its characteristic caseous odour, and the differences in its pungency or aromatic flavour depend upon the proportion of free butyric, capric, and caproic acids present.

The transition of caseine from its insoluble into its soluble state depends upon the decomposition of the phosphate of lime by the margaric acid of the butter: margarate of lime is formed whilst the phosphoric acid combines with the caseine, forming a compound soluble in water.

The bad smell of inferior kinds of cheese, especially those called meagre or poor cheeses, is caused by certain fetid products containing sulphur, and which are formed by the decomposition or putrefaction of the caseine. The alteration which the butter undergoes (that is, in becoming rancid), or which occurs in the milk-sugar still present, being transmitted to the caseine, changes the composition of the latter substance and deteriorates its nutritive properties.

The principal conditions for the preparation of the superior kinds of cheese (other obvious circumstances being, of course, duly regarded) are, a careful removal of the whey, which holds the milk-sugar in solution, and a low temperature during the maturation (or ripening) of the cheese.*

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* The quality of Roquefort cheese, which is prepared from sheep's milk, and is very excellent, depends exclusively upon the places where the cheeses are kept after pressing, and during maturation. These are cellars, communicating with mountain grottoes and caverns, which are kept constantly cool, at about 41° to 42° Fahr., by currents of air from the clefts in the mountains. The value of these cellars, or storehouses, varies with their property of maintaining an equable and low temperature. Giron (Ann. de Chimie et de Physique, xlv. 371) mentions, that a certain cellar, the construction of which had cost 480*l*. (12,000 francs), was sold for 8600*l*. (215,000 francs), being found to maintain a suitable temperature. A convincing proof of the importance attached to temperature in the preparation of these superior cheeses.

The differences in flavour and odour of various kinds of cheese depend upon the methods employed in their manufacture—upon the state of the rennet when added to the milk—upon the addition of salt, and upon the state of the atmosphere during the period of making. It must be admitted that the plants, and especially the aromatic plants, upon which the animals feed, exercise some influence upon the quality of the cheese ; but this influence is very slight and subordinate. The milk of the cow in spring, summer, and autumn, is very unequal in its composition, but this does not occasion any perceptible difference in the cheese prepared in one and the same dairy. If the plants upon which the cows feed exercised any considerable influence upon the quality of cheese, the same pastures could not, at different seasons, furnish cheese of similar quality, inasmuch as the development and flowering of different species of plants belong to various seasons.

I have, by personal inspection, satisfied myself that the method of preparing the cheese is quite different in Cheshire from that practised in Gloucestershire, and this, again, differs from the plan pursued in the manufacture of Stilton cheese.

The lining membrane of the stomach of the calf, and the mucous membrane of the stomach of animals generally, besides the power of converting milk-sugar into lactic acid, possess the property of rendering soluble, or liquefying, solid animal matters, when weak hydrochloric acid is present. The phenomena observed in this chemical operation have thrown a new and unexpected light upon the process of DIGESTION in the living animal organism. All ferments, as they are called, that is, substances which are capable of exciting fermentation, possess also, in a certain stage of their transformation, this power of liquefying and rendering soluble various aliments. We have already seen that extract of malt, and gluten, possess this power in reference to starch, but these are far surpassed in this property by the mucous membrane of the stomach. If a small portion of calf's stomach or rennet is placed for a few hours in warm water, mixed with so small an amount of hydrochloric acid as scarcely to impart an acid taste to the water, a solution is obtained which acts upon boiled meats, upon gluten, and upon hard-boiled white of egg, in exactly the same manner as the gastric juice in the living stomach. This artificial digestive fluid is like gastric juice, inasmuch as both have an acid reaction, owing to the presence of hydrochloric acid. When pieces of muscular fibre, or hard-boiled albumen, are exposed in this artificial digestive fluid to a temperature of 37° C. (the temperature of the stomach = 98·6° Fahr.), they speedily become slimy, and transparent at the edges, and after the lapse of a few hours they become dissolved in a fluid rendered slightly turbid by particles of fat. The dissolving power of the hydrochloric acid, *per se*, becomes, by the addition of a scarcely ponderable amount of mucous membrane, in a state of decomposition, accelerated so greatly, that solution takes place in a fifth part of the time which is required under ordinary circumstances.

Physiologists have observed that in digestion the whole of the inner surface of the membrane of the stomach, *the epithelium*, separates completely from the other layers of the membrane.

It cannot be disputed that this *epithelium*, in coming into contact with the oxygen which the saliva carries into the stomach, inclosed in its air bubbles or froth, undergoes an alteration, in consequence of which the contents of the stomach are dissolved in the shortest possible time.

It was for a long time believed that the accelerated dissolving power, which the mucous membrane of the stomach imparts to the hydrochloric fluid, depended upon the presence of a particular substance called *pepsine*, a kind of digestive agent. The same opinion prevailed respecting a substance called *diastase*, contained in the extract of malt, by which starch is converted into sugar; and these substances have received certain designations.

But what have been called *pepsine* and *diastase* are nothing more than a portion of mucous membrane, or of gluten having passed into a state of decomposition. The action of these bodies depends entirely upon their condition, just as is the case with yeast.

With a piece of the mucous membrane of the stomach, in a certain stage of decomposition, we may render certain animal substances soluble; whilst, with the same membrane, in other stages of decomposition, we may convert starch into sugar, sugar into *lactic acid*, *mannite*, and *mucus;* or, into *alcohol* and *carbonic acid:* and lactic acid into butyric acid, hydrogen and carbonic acid.

In the same manner a watery infusion of fresh malt will convert starch-paste, in the space of a few minutes, into grape-sugar. The infusion or extract of malt loses this property after the lapse of a few days, and, in its stead, acquires the power of converting grape-sugar into lactic acid, mannite, and gum. And, again, after eight or ten days, the infusion becomes turbid, and it now causes the resolution of the sugar atom into alcohol and carbonic acid.

The phenomena we have described, if considered in their true signification, prove that the decompositions and transformations which occur in the processes of fermentation, are effected by matter, the smallest particles or atoms of which are in a state of motion and transposition,—a state susceptible of being communicated to other atoms in contact with the former, so as to cause the atoms and elements of these latter also, in consequence of the resulting disturbance of the equilibrium of their chemical attraction, to change their position, and to arrange themselves into one or more new groups.

We have observed that the products formed during fermentation alter with the temperature, and with the state of transformation in which the particles of the ferment exist. Hence it is obvious that the new manner of molecular arrangement, which determines the nature and properties of the new-formed products, stands in a definite and immediate relation to the mode and manner, direction and energy, of the motion and force acting upon them.

All organic substances become exciters of fermentation as soon as they pass into a state of decomposition; the changing condition once imparted, propagates itself in every organic atom, which is not itself, that is, by its own inherent energy, capable of annihilating the imparted motion, by presenting an adequate resistance.

Putrescent flesh, blood, bile, urine, the mucous membrane of the stomach, have this property in common with substances occurring in certain parts of plants, or in the vegetable juices. All substances capable of exciting fermentation, that is, as we understand it, all those complex atoms which, upon the mere contact of water or of oxygen, pass into a state of decomposition, possess certain properties in common; but every one of these, also, produces certain effects peculiar to itself, and it is in this respect they differ essentially from each other. These latter peculiar and individual actions and effects stand in the closest relation to their composition. Thus, the vegetable caseine of almonds acts upon starch and sugar precisely like gluten or yeast; but gluten and yeast are not capable of resolving *salicine* into saligenine and sugar, or amygdaline into hydrocyanic acid and oil of bitter almonds.

In like manner, animal membranes, in a certain condition, acquire all the properties of fermenting animal cheese or caseine, but the latter substance has no perceptible influence upon the solvent power of hydrochloric acid, upon the liquefaction of coagulated albumen and flesh.

All the phenomena of fermentation when taken together establish the correctness of the principle long since recognised by Laplace and Berthollet, namely, *that an atom or molecule put in motion by any power whatever may communicate its own motion to another atom in contact with it.*

This is a dynamical law of the most general application, manifested everywhere, when the resistance or force opposing the motion, such as the vital principle, the force of affinity, electricity, cohesion, &c., is not sufficiently powerful to arrest the motion imparted.

This law has only recently been recognised as a cause of the alterations in forms and properties which occur in our chemical combinations ; and its establishment is the greatest and most enduring acquisition which chemical science has derived from the study of fermentation.

LETTER XVII.

THE immediate and most energetic cause of all the alterations and transformations which organic atoms undergo is, as I have already stated, the chemical action of oxygen. Fermentation and putrefaction manifest themselves only in consequence of the commencement of a process of decay ; their completion is the restoration of a state of equilibrium. Whilst the oxygen is in the act of combining with any one of the elements of an organic substance, the original state of equilibrium of attraction in all its elements is destroyed, the substance decomposes, resolving itself—all the molecular attractions being again equalised—into a series of new products, which undergo no further change in their properties unless further causes of disturbance or alteration are brought to operate upon them.

But although the chemical action which the elements of organic atoms exercise upon each other in fermentation and putrefaction balances itself, in such a manner that a state of rest is induced between the attractions of the new formed products, yet this equilibrium does not exist with respect to their attraction for oxygen. The chemical action of oxygen upon organic substances ceases only when the capacity of the elements to combine with oxygen is exhausted. That action consists in nothing more than the affinity, or tendency of the oxygen to combine with those elements. A perfect equalisation of this tendency, therefore, can only ensue when the elements, by combining with oxygen, have formed such products as are totally incapable of absorbing any additional amount of oxygen. It is only then that the attractions of the elements of organic substances attain a perfect equilibrium with those of oxygen.

Fermentation or putrefaction represents the first stage of the resolution of complex atoms into more simple combinations: the process of decay completes the circulation of the elements by transposing the products of fermentation and putrefaction into gaseous compounds. Thus the elements constituting all organised beings, which previously to participating in the vital process were in the forms of oxygen compounds, —their carbon and hydrogen, reassume the form of oxygen compounds. *The process of decay is a process of combustion taking place at the common temperature,** in which the products of the fermentation and

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* In order to avoid the ambiguity attached to the word *decay*, from its being in vernacular language applied to several processes

putrefaction of plants and animal bodies combine gradually with the oxygen of the atmosphere.

No organised substance, no part of any plant or animal, after the extinction of the vital principle, is capable of resisting the chemical action of air and moisture ; for all the power of resistance which they temporarily possessed as the bearers of life, as the seat of the vital manifestations, completely ceases with the death of the organism ; their elements fall again under the unlimited dominion of the chemical forces.

The clearing of the primeval forests of America, facilitating the access of air to that soil, so rich in vegetable remains, alters gradually, but altogether, its constitution : after the lapse of a few years no trace of organic remains can be found in it. The soil of Germany, in the time of Tacitus, was covered with a dense, almost impenetrable, forest ; it must at that period have exactly resembled the soil of America, and have been rich in humus and vegetable substances ; but all the products of vegetable life in those primeval forests have completely vanished from our perceptions. The innumerable millions of molluscous and other animals, whose remains form extensive geological formations and mountains, have, after death, passed into a state of fermentation and putrefaction, and subsequently, by the continuous action of the atmosphere, all their soft parts have been transposed into gaseous compounds, and their shells and bones, their indestructible constituents, alone remain, to furnish evidence of the past existence of life, continually extinguished, and continually reproduced.

It is only in localities, under peculiar circumstances, where the access of oxygen was limited or altogether precluded, that we still find distinct remains of

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which it is desirable to distinguish, the author proposed to substitute the term EREMACAUSIS, and this has been very generally adopted in scientific treatises, being a convenient mode of expressing the relation of decay to ordinary combustion.

primeval vegetables in a state of retarded or impeded decay, as for example, in beds of turf and brown coal.

The presence of water and a suitable temperature are indispensable conditions of the oxidising process of decay, just as they are necessary to putrefaction and fermentation. Perfect dryness, or a temperature below the freezing point, suspends all processes of decay and fermentation. The transmission of decomposition from one particle to another presupposes a change of place ; it requires that the particles should possess mobility, or the power of free motion, and this is imparted to them by the presence of water. In decay it is more especially a certain elevated temperature which increases the aptitude of the elements of organic substances to combine with the oxygen of the atmosphere.

A great number of organic bodies, when in a moist state, are capable of absorbing oxygen, whilst many, and indeed most of them, are *per se* entirely deficient in this property.

If we place wet hay, or moistened fragments of wood, in a vessel filled with atmospheric air, all the properties of the contained air become in a very short time completely altered. If a lighted splinter,—which of course would burn in atmospheric air,—is introduced after the lapse of two or three hours, its flame will be immediately extinguished. The air confined in the vessel, if examined, will be found to have lost all its oxygen, and to have acquired an equal volume of carbonic acid gas. If a fresh supply of atmospheric air is made to replace this, the same process again occurs, all the oxygen becomes converted into carbonic acid. Exactly the same result would have been attained, had we burned the hay or wood in the confined air.

In the process of bleaching in the open air, or, as it is called, grass-bleaching, we have the process of decay applied to an important purpose in the arts upon a large scale. Linen or cotton textures consist of ordinary wooden fibre, more or less coloured by extraneous organic substances, which were either contained in the plant whence the fibre has been derived, or have become mixed with it during the processes of preparation.

When linen or cotton fabrics are moistened with water and exposed to the light of the sun, a slow process of combustion, or decay, immediately begins upon the whole surface ; the oxygen of the atmosphere in immediate contact with the linen or cotton is incessantly converted into carbonic acid. The weight of the fabric diminishes every second, precisely because it is in a state of combustion ; all the colouring matters gradually disappear, and with them a considerable amount of woody fibre, their elements being converted into oxygen compounds. If this action of air and light upon the linen or cotton continues for a considerable time, these substances lose their cohesion and become converted into a matter similar to that used in the manufacture of paper, and this matter still continues to decay as long as the essential condition of this change, that is, the absorption of oxygen, continues.

The nitrogenous constituents of plants and animals comport themselves towards oxygen in a manner precisely similar to the behaviour of the non-nitrogenous principle we have spoken of; namely, woody fibre. Fresh meat, as well as the first products of the decomposition of the nitrogenous constituents of plants in fermentation, that is, beer-yeast, or wine-yeast, withdraw oxygen from atmospheric air, and, like woody fibre, yield in return an equal volume of carbonic acid.

When the Cemetery of the Innocents at Paris was removed from the interior of the town to the outside of the barriers, the buried corpses, which had accumulated to a depth of sixty feet, were found to a great extent apparently converted into fat. The substance of the skin, muscles, cellular tissue, and tendons, all the soft parts, and even the bones, had completely disappeared, leaving only the fat, which resisting longest the influence of decay, remained in the form of margaric acid. This human fat was employed to the extent of many tons by the soap-boilers and tallow-chandlers of Paris, for the manufacture of soap and candles.

If meat be suspended in running water, or buried in moist earth, nothing of it will remain after the lapse of some time, except the fat which it contains.

All substances susceptible of decay, when in a moist state, and exposed to the air and light at the common temperature, undergo precisely the same change as they would if exposed to a red-heat, in a dry state; that is, they absorb oxygen,—they undergo combustion.

Alcohol, one of the products of the fermentation of saccharine vegetable juices, is altogether incapable of undergoing the process of decay; when exposed to the air, whether in its pure state or mixed with water, it evaporates without combining with oxygen. Alcohol is readily inflammable at a higher temperature, and in burning is resolved into carbonic acid and water. It is obvious that its elements have a powerful affinity for oxygen; the high temperature is, however, a necessary condition of the manifestation of this affinity. Hydrogen gas and many other inflammable substances are, in this respect, precisely similar to alcohol; their affinity for oxygen manifests itself only at certain high temperatures.

In the process of decay it has been likewise observed that a substance undergoing this state of elementary transposition exercises a remarkable influence upon the particles of an adjacent substance, which *per se* would not be capable of passing into the same state of change, decay, or transposition.

Many substances, when in contact with another in a state of decay, manifest, at common temperatures, an affinity for oxygen ; that is, they enter into combination with this element, at this low temperature, whilst under other circumstances such a combination can only be effected by a far higher degree of heat.

The state of active absorption of oxygen, the combustion of the decaying substance, is transmitted to the particles of other substances in contact with it; they assume its characteristic state of activity: they behave as if they formed part of the decaying body, and their combination with oxygen is effected, in a manner not further explicable, just as it is by heat. Contact with a substance, itself undergoing the process of decay, is the chief condition of decay for all organic substances which do not possess the power of combining with oxygen at common temperatures. In consequence of the ensuing combination of its elements with oxygen, the temperature of the decaying substance rises above that of the surrounding medium; but great as the influence is which heat exercises in accelerating the process, it is not in this, as in other chemical processes, the cause of the manifestation of the affinity for oxygen.

If, in a vessel filled with common atmospheric air, to which a certain amount of hydrogen gas has been added, a linen bag be suspended, filled with wet sawdust, vegetable mould, &c., the process of decay will continue just as it would if they were exposed to the open air. They will convert the surrounding oxygen into carbonic acid. But what is very remarkable in this case, the hydrogen also participates in the process—it undergoes decay; that is, from being in contact with decaying substances, it acquires the power of combining with oxygen at the common temperature. If there be a sufficient amount of oxygen present, all the hydrogen gas is converted into water.

Other inflammable gases, both simple and compound, are affected under these circumstances in exactly the same manner as hydrogen. The vapour of alcohol, for example, when in a vessel containing wood or other substances in a state of decay, absorbs oxygen from the atmosphere, and becomes transformed into aldehyde, and subsequently into acetic acid, which, upon assuming a fluid state, is withdrawn from the further influence of the oxygen.

It is upon this power of substances undergoing decay, to increase the attraction of all organic substances for oxygen, and especially the affinity of alcohol for this element, that a speedy process for acidifying alcohol was based, which is termed the "Schnellessigfabrikation," or "quick vinegar process."

The transformation of fermented liquors into vinegar formerly required weeks, and even months, to accomplish, in consequence of the imperfect access of the air: we can now convert alcohol into vinegar in less than twenty-four hours; and this is effected mainly by making brandy diluted with water, or any other weak spirituous liquor, trickle slowly through casks filled with wood shavings, and at the same time causing a slight stream of air to circulate through these shavings. This method exposes to the air a surface of alcohol capable of absorbing oxygen, by many thousand times more extensive than the old method; and consequently the time which alcohol, under ordinary circumstances, requires for its acidification, is abridged in the same proportion. At the commencement of this process it is usual to add to the dilute spirit a small quantity of some substance containing matter capable of undergoing the process of decay, such as beer-wort, honey, vinegar, &c.; but, after the lapse of a very short time, the surface of the wood-shavings passes into a state of oxidation, and from that moment effects the transformation of the spirit into vinegar without the further co-operation of extraneous decaying matter.

The origin of nitric acid or nitrates (nitrification), and the occurrence of these salts in certain kinds of garden mould and fertile soil, in the earth floors or in the walls of cowhouses, stables, or other houses, and in the spring water of towns and villages, depends on the same general cause, as the formation of acetic acid from alcoholic liquids. The nitric acid is produced from the ammonia, one of the ultimate products of putrefaction of animal, or rather, of nitrogenous substances.

When ammonia is in contact with decaying matters, and when lime or magnesia, and a certain amount of moisture are present, the elements of ammonia, its nitrogen and hydrogen, unite with the oxygen of the air to form nitric acid and water, and the acid forms salts, that is, nitrates, with the alkalies or alkaline earths.

The crystalline salts, which often effloresce on the walls of stables and cowhouses, and in places moistened with the liquid of sewers, are nitrates, usually nitrate of lime, a salt, which deliquesces in moist air, and by the presence of which the walls become continually moist and damp. The lime is derived from the mortar or plaster.

A great part of the nitre (nitrate of potash) used for the manufacture of powder in France, is obtained, in Paris, from the lower stones of the houses, which are constantly in contact with the liquids of the streets and drains. The lime of the walls is gradually dissolved by the nitric acid formed; the walls lose their coherence and firmness; hence the name of wall-corrosion (in German, Mauerfrass) given to this injurious formation of nitre. The potash of the nitre is generally derived from bricks, and even the mortar contains some potash, which gradually decomposes the nitrate of lime, aided by the superior crystallising power of nitre, so that the latter salt is formed. But generally, in order to obtain all the nitric acid as nitre, potash must be added to the liquid obtained from the scrapings of the walls by lixiviation with water.

The application of our knowledge respecting the phenomena attendant upon decay, to the manufacture of beer and wine, is easy and obvious. The property of beer and wine to be converted into vinegar when in contact with the air, depends invariably upon the presence of foreign matters which transmit their own inherent aptitude to absorb oxygen to the particles of alcohol in contact with them. By removing completely all such substances from wine and beer, these lose altogether the property of acidifying, or of being converted into vinegar.

In the juice of grapes poor in sugar there remains, after the completion of the process of fermentation—that is, after the resolution of the sugar into carbonic acid and alcohol—a considerable amount of nitrogenous constituents retaining the same properties which they possessed in the juice previous to fermentation. This does not happen with the juice of the grapes of southern climates. These grapes are rich in sugar, and a considerable amount of this substance remains undecomposed after all nitrogenous matters have completely separated in an insoluble state, as yeast. Such wines alter very little when exposed to the air: the red wines of this kind, however, acidify because their colouring matter is of ready mutability, and performs, when in contact with the air, the part of the nitrogenous constituents.

The nitrogenous constituents of the grape-juice which remain in wine, after fermentation, are those ferments, or exciters of fermentation in the sugar, of which I have already spoken in previous letters. After the complete transformation of the sugar, they exercise upon the alcohol exactly the same effect as the decaying wood—they are the exciting causes of the ensuing process of acidification.

The affinity of these substances for oxygen is very powerful; during the short space of time necessary to transfer wine from one cask into another, they absorb oxygen from the air, and induce a state of acidity in the wine, which goes on irresistibly if it be not checked by artificial means. It is well known that this check is practically effected by sulphuration. A piece of sulphur is burned in the cask destined to receive the wine, the contained air is thus deprived of its oxygen, and an amount of sulphurous acid is formed equal to the volume of the oxygen. This newly-formed sulphurous acid is rapidly absorbed by the moist internal surface of the cask. Sulphurous acid possesses a stronger affinity for oxygen than the exciters of acidification in the wine. The acid is gradually diffused from the internal surface of the cask through the wine, and withdraws from those substances, as well as from the wine itself, all the oxygen they have absorbed from the atmosphere, and thus reconverts the wine into the state in which it existed previously to being transferred into the new cask. The sulphurous acid in this process becomes converted into sulphuric acid, and exists as such in the wine.

When the wine is stored up in casks to ripen, a constant, although very slow, diffusion of air takes place through the pores of the wood, or, what comes to the same thing, the wine is incessantly in contact with a minute amount of oxygen; by means of which, after the lapse of a certain time, the entire quantity of the exciters of acidification, that is, the nitrogenous substances present in the wine, oxidise and separate in the form of a sediment or dregs, termed under-yeast, or sedimentary yeast.

The separation of yeast from wine or beer, during the fermentation of grape-juice or of worts, takes place in consequence of the absorption of oxygen, or, in other words, is a process of oxidation, occurring in the fermenting liquid. The nitrogenous constituent of barley is in its primary state insoluble in water, but in the process of malting, or whilst the grain is germinating, it becomes soluble in water, it assumes the same condition or nature which belongs to the nitrogenous constituent of grape-juice originally.

Both these substances lose their solubility in wine, or in beer, by absorbing oxygen. According to analyses in which we may confide, made with regard to this point, wine-yeast and beer-yeast are far richer in oxygen than the nitrogenous substances from which they are derived.

As long as any particles of sugar, in a state of fermentation, are present in the fluid together with these nitrogenous matters, the fluid itself supplies the oxygen required for their transformation into yeast by the decomposition of a small amount of the sugar or of water. This oxidising process within the fluid itself, which causes the nitrogenous constituents to become insoluble, ceases with the disappearance of the sugar ; but it is renewed if the fluid is reconverted into a fermenting state, by the addition of new portions of sugar, and it ensues also when the surface of the fluid is exposed to the free access of the atmosphere. In the latter case the separation of the nitrogenous constituents is effected by the atmospheric oxygen, and is thus a consequence of their decay or slow combustion.

I have already stated that the presence of nitrogenous matters in alcohol causes the transformation of the alcohol into acetic acid when there is a sufficient supply of air ; now it is owing to the inequalities in their relative affinities for oxygen, that during the maturation of wine in the storehouse, when the access of air is extremely limited, that the nitrogenous substances alone oxidise, and not the alcohol. In open vessels, under these circumstances, the wine would become converted into vinegar.

The preceding remarks render it obvious that if we possessed any means of preventing the transformation of alcohol into acetic acid we should be able to preserve wine and beer for an unlimited period, and to bring those liquors into a state of perfect maturity ; for, under such circumstances, all those substances which cause wine and beer to acidify would become insoluble by combining with oxygen, and separate from the liquid, and with their perfect removal the alcohol present would altogether lose the property of absorbing oxygen.

Experimental art has discovered a means of accomplishing this purpose perfectly. It consists in keeping the fluid at a low temperature when undergoing fermentation. The method, based upon this principle, and employed in Bavaria, is one which the most perfect theory could scarcely have surpassed in certainty and simplicity, and it seems impossible to devise one more in accordance with science.

The transformation of alcohol into acetic acid by contact with a substance in a state of decay occurs most rapidly at a temperature of 95° Fahrenheit. At lower temperatures the affinity of alcohol for oxygen decreases, and at from 46° to 50° Fahrenheit no combination with oxygen takes place under these circumstances, whilst the tendency of nitrogenous substances to absorb oxygen at this low temperature is scarcely diminished in any perceptible degree.

It is, therefore, obvious that if wort be fermented in wide, open, and shallow vessels, as is done in Bavaria, which afford free and unlimited access to the atmospheric oxygen, and this in a situation where the temperature does not exceed 46° to 50° Fahrenheit, a separation of the nitrogenous constituents, *i.e.*, the exciters of acidification, takes place simultaneously on the surface, and within the whole body of the liquid. The clearing of the beer is the sign by which it is known that these matters are separated. A more or less perfectly complete removal of these nitrogenous substances, however, according to this method of fermentation, depends upon the skill and experience of the brewer. It may be easily conceived that an absolutely perfect separation of them is attained only in rare and extremely happy instances. Nevertheless, the beer obtained in this manner is invariably far superior in quality and stability to that brewed according to the common method.

The exceedingly favourable influence which the adoption of this principle must exercise upon the manufacture of wine is indisputable. It is too evident to admit of a doubt that it will lead to the adoption of a more rational method than has hitherto been employed.

Wine prepared by this method will, of course, bear the same relation to the wine prepared in the ordinary way, that Bavarian beer bears to common beer, in the fabrication of which the same amount of malt and hops has been employed. In the shortest possible time the same quality, the same maturity, may be attained by the wine which, under ordinary circumstances, would result, only after long and protracted storing. If it be borne in mind that the period for the manufacture of wine is the end of October, just at the cool season which is peculiarly favourable to the fermentation of beer, and that no other conditions are necessary to the vinous fermentation than a cool cellar, and open, wide fermenting vessels, and further, that under all circumstances the danger of acidification is much less with wine than with beer, it is evident that the best success may confidently be expected from the application of this method.*

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* One of the most intelligent agriculturists and wine-growers of the Grand Duchy of Baden, Baron von Babo, remarks, in a letter to me, dated April, 1843, "With respect to the application of the Bavarian method of fermentation to the manufacture of my red wine last autumn, I am happy to inform you that it answered excellently. Our wine-makers cannot understand the matter, clear and obvious as it is, that the method which it is universally acknow-

It must not be forgotten, that wine contains a much smaller proportion of nitrogenous matters after fermentation, than beer-worts, and that a much more limited access of air is required for its complete oxidation and separation in an insoluble form.

The method employed at most places on the Rhine proceeds upon principles the very reverse of this. The wine is left to ferment, not in cool cellars, but in rooms, situate much too high and too warm; the access of air is completely precluded during the process of fermentation by tin-plate tubes, confined with water. These tubes certainly exercise an injurious effect upon the quality of the wine; they are, in every respect, futile—the invention of some idle brain; they serve no object, and yet they are used by people who imitate others, without assigning any reason for doing so.

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ledged yields most excellent results in the manufacture of beer, should be as advantageously applied to making wine."

An experiment made with red wine in the autumn of 1841, by the same nobleman, had afforded the same favourable results, especially as to the colour of the wine. Before these successful experiments it might have been thought that *red* wine was the rock upon which this method would founder, but we are now assured of its universal adaptation to the manufacture of wines. Experiments on the great scale, made in 1846 on the Johannisberg, with six casks of juice, each of 1200 bottles capacity, most kindly granted by Prince Metternich, under the direction of the experienced wine-grower Herr Heckler, have proved, that the access of air during the fermentation exercises an essentially favourable influence on the quality of the wine. In each of the casks a hole of twelve inches square was cut at the bung, and it appeared, that an opening of six inches square, covered with coarse canvas, answers perfectly, and that the wine thus fermented had an evidently better quality than that fermented with the fermenting pipe, air being excluded. Exactly similar results were obtained by Dr. Crasso, when he fermented the juice in casks, the tops of which were taken off, and used as loose covers during the process.—(Annalen der Chemie und Pharmacie, lix. p. 360). In other experiments, in which the wine fermented in open vats, it lost its *bouquet* and became flat.

LETTER XVIII.

THE property of organic substances to pass into a state of fermentation and decay, in contact with atmospheric air, and, in consequence, to transmit these states of transmutation to other organic substances, is annihilated in all cases, without exception, by heating to the boiling point. This is certainly the most striking and evident proof that the ready mutability of these substances is connected with a certain mode of arrangement of their component atoms. We need only consider the coagulation of albumen by heat, to understand the manner in which heat acts in producing this effect. Most ferments have a constitution analogous to that of albumen, and, at a higher temperature, pass into a new state.

When sweet almonds are blanched, and allowed to remain even only a few seconds in boiling water, their power of acting upon amygdaline is completely annihilated. Amygdaline dissolves without alteration in almond-milk which has been heated to the boiling point. Malt altogether loses, by boiling, its property of converting starch into sugar. A watery infusion of beer-yeast, in which cane-sugar instantly passes into grape-sugar, and the juice of diseased potatoes, in which the substance of the cells of sound ones is disintegrated and rendered soluble, both lose, when heated to boiling, these properties entirely.

Fresh animal milk, as is well known, coagulates, after being kept for two or three days, into a gelatinous mass. If fresh milk be heated daily to the boiling point it may be preserved for an indefinite period. Grape-juice, so readily mutable, and every fluid susceptible of fermentation, is affected in the same manner; when heated to the boiling point all fermentation in them ceases. Beer-wort, after boiling, requires the addition of yeast, that is, an extraneous substance already itself in a state of decomposition, in order to ferment in the shortest possible time.

It is obvious that if that particular state into which an organic substance is brought by contact with the atmosphere,—although this contact may have been but for an instant,—be destroyed by a high temperature, and oxygen (the only cause of its re-appearance) from the time of its boiling be excluded, these substances must, for an unlimited period, retain all the properties they possessed at the moment of boiling. Matter *per se* has no inherent power of mobility; without the influence of some external force upon the atoms, none of them change their place, none alter their properties.

If a bottle be filled with grape-juice and made air-tight, and then kept for a few hours in boiling water, or until the contained grape-juice has become throughout heated to the boiling point, the minute amount of oxygen contained in the air which entered the flask with the grape-juice becomes absorbed during the operation by the constituents of the juice, and thus the cause of further perturbation is removed. The juice does not now ferment, but remains perfectly sweet until the flask is again opened, and its contents brought into contact with the air. From this moment the same alteration begins to manifest itself which fresh juice undergoes; after the lapse of a few hours the contents of the flask are in full fermentation, and this state may be again interrupted and suspended, as at first, by repeating the boiling.

The knowledge of these properties, which are equally possessed by all other organic substances, without exception, has given rise to the most beautiful practical applications of them. Whilst, in former times, during long voyages, mariners were confined to salt and smoked meats, which, in the long run, always proved injurious to the health of the crew and the passengers, and thousands of human beings lost their lives for the want of fresh aliments, which were even more essential in sickness, these dangers and discomforts become more and more rare at the present day. This is certainly one of the most important contributions to the practical benefit of mankind ever made by science, and for this we are indebted to Gay-Lussac.

At Leith in the neighbourhood of Edinburgh, at Aberdeen, at Bordeaux, Marseilles, and in many parts of Germany, establishments of enormous magnitude exist, in which soup, vegetables, animal substances, and viands of every description are prepared and sent to the greatest distances. The prepared aliments are enclosed in canisters of tinned iron plate, the covers are soldered air-tight, and the canisters exposed to the temperature of boiling water. When this degree of heat has penetrated to the centre of the contents, which it requires about three or four hours to accomplish, the aliments have acquired a stability which, one may almost say, is eternal. When the canister is opened after the lapse of several years, the contents appear just as if they were only recently enclosed. The colour, taste, and smell of the meat are completely unaltered. This valuable method of preparing food has been adopted by many persons in my neighbourhood and other parts of Germany, and has enabled our housewives to adorn their tables with green vegetables in the midst of winter, and with dishes at all times which otherwise could be obtained only at particular seasons. This method of preserving food will become of the greatest importance in provisioning fortresses, since the loss incurred in selling off old stores, and replacing them by new, especially with respect to meat, ham, &c., is far more considerable than the value of the tin canisters, which, moreover, may be repeatedly employed after being carefully cleansed.

When we compare the phenomena of putrefaction and fermentation with the processes in the living animal body, it becomes very probable, that a number of effects, which we are accustomed to refer to peculiar vital influences, are determined by the same causes on which fermentation and putrefaction depend. These analogies have been noticed and pointed out for centuries by philosophers and physicians; but even now many of the latter class consider, in opposition to the view here developed, certain vital actions or manifestations of vitality as the causes of putrefaction and fermentation.

It has been stated above that the constituents of the mass of the body, albumen, fibrine, membranes, skin, and caseine, when putrescent, exert a peculiar influence on many substances, the visible result of which is a chemical change in the substance brought in contact with these compounds. It is further an established fact, that the products derivable from the substances thus acted on are not always the same, but vary with the state of decomposition of the ferment or exciting body.

But if a change of position and arrangement in the particles of animal substances can exert, *out of the body*, a very decided influence on a number of organic compounds; if the latter, when in contact with these ferments, are decomposed, and new compounds, less complex, formed of their elements, and if we reflect that to the class of fermentescible substances *belong all the matters which constitute the various articles of the food of men and animals*, then we can hardly doubt that this cause of change plays an important part in the vital processes, and has a chief share in producing the changes which the constituents of the food undergo, when they are converted, in the body, into fat or into tissues forming parts of organs, or in the formation of the secretions and excretions, such as milk, bile, urine, &c. We know, indeed, that in all parts of the living animal body a change of matter is going on at every moment of time; that living parts are expelled; that their constituents, albumen, fibrine, membranes, and all the rest, whatever their names, arrange themselves in the moment of their separation from the living tissue, and, subsequently, into new products; and our experience compels us to conclude that by this change of quality and composition itself, at every point where it occurs, and according to its force and direction, a parallel and corresponding change is effected in the composition and quality of all the constituents of the blood, or the food, which come into contact with them, and that, consequently, the change of matter is a chief cause of the changes which the food undergoes, and also a condition of the process of nutrition; that with every change effected by a cause of disease in the process of transformation of an organ, of a gland, or of a constituent of these, the action of that organ on the blood conveyed to it, that is, the quality of its secretion, is likewise altered; that the action of a multitude of remedies depends on the share which they take in the change of matter; and that, in many cases, this action of remedies, by changing, accelerating, retarding, or arresting the direction or the force of the agency which operates in the organ, exerts an influence on the quality of the blood.

Finally, by a knowledge of the causes of the origin and propagation of putrefaction in organic atoms, the question concerning the nature of many contagions and miasms becomes capable of a simple solution, and may be reduced to the following:

Are there facts which prove that certain states of transformation or putrefaction in a substance are likewise propagated to parts or constituents of the living animal body; that, by contact with the putrescent matter, the same or a similar condition is produced on such parts, as that in which the particles of the putrescent body are? This question must be answered decidedly in the affirmative.

It is a fact, that dead bodies in dissecting-rooms frequently pass into a state of decomposition which is communicated to the blood in the living body. The slightest cuts with the scalpels used in dissecting often cause a very dangerous and even fatal disease.* The observation of Magendie, that putrid blood, brain, bile, or pus, when laid on fresh wounds, produce in animals vomiting, languor, and death after a shorter or longer interval, has not yet been contradicted. *See* Appendix, No. 3.

Further, it is a fact, that the use of various articles of food, such as flesh, ham, sausages, if in a certain state of decomposition, is followed, in healthy persons, by the most dangerous and even fatal symptoms. *See* Appendix, No. 4.

These facts prove that an animal matter, in a certain state of decomposition, is capable of exciting a morbid action in the body of healthy individuals. Now, since by the term, products of diseased action, nothing else can be meant than parts or constituents of the living body which are in a state of change in form and quality different from the normal one, it is evident, that, so long as this state continues, and the change is not completed, the disease may be communicated to a second or third individual, and so on.

Besides, when we consider, that all those substances which destroy the communicability or arrest the propagation of contagions and miasms, are likewise such as arrest all processes of putrefaction or fermentation; that under the influence of empyreumatic

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* Cases in which anatomists fall victims to this frightful kind of poisoning are not rare; as in the recent melancholy examples of Dr. Kolletschka in Vienna, Dr. Bender in Frankfort-on-the-Maine, and many others.

bodies, such as pyroligneous acid, which powerfully oppose putrefaction, the diseased action in malignant suppurating wounds is entirely changed; that, in a number of contagious diseases, especially in typhus, ammonia, free or combined, is found in the exposed air, in the liquid and solid excreta, (in the latter as ammonio-phosphate of magnesia), it seems impossible any longer to entertain a doubt as to the origin and propagation of many contagious diseases.

Finally, it is an observation universally made, and which may be regarded as established, "that the origin of epidemic diseases may often be referred to the putrefaction of great masses of animal and vegetable matters; that miasmic diseases are found epidemic, where decomposition of organic substances constantly goes on, in marshy and damp districts. These diseases also become epidemic, under the same circumstances, after inundations; and also in places where a large number of persons are crowded together with imperfect ventilation, as in ships, in prisons, and in besieged fortresses." (Henle, Untersuchungen, p. 52; also p. 57.) But in no case may we so securely reckon on the occurrence of epidemic diseases, as when a marshy surface has been dried up by continued heat, or when extensive inundations are followed by intense heat.

Hence, according to the rules of scientific research, the conclusion is entirely justified, that, in all cases, where a putrefactive process precedes the occurrence of an epidemic or contagious disease, or where the disease can be propagated by means of solid, liquid, or gaseous products of diseased action, and when no other cause for the disease can be discovered, the substances which are in a state of transformation are, in virtue of that state, to be regarded as the proximate causes of the disease.

The well-informed and attentive physician has been long aware that the difference between good and wholesome food, and that which is bad, which latter is justly regarded as the cause of many diseases, depends, not on the nature of the food, but on a certain quality or state of it, which, in the case of flesh, for example, can often be referred to a diseased state of the animal from which it was taken. He knows that the useful and beneficial effects of a proper ventilation on the preservation of health, may be often attained, in the chamber of the sick, for example, by the evaporation of small quantities of nitric acid (not of chlorine, which, in most cases, has an injurious, or at least an irritating, effect), or by the burning of a little sulphur; by means of substances, therefore, of which we know that they destroy noxious gases, or put an end to their state of decomposition.

LETTER XIX.

SOME philosophers, and especially many physiologists and medical men, have adopted a peculiar view concerning the causes of the appearances, so remarkable in themselves, which occur after the death of plants and animals, and which effect their resolution into inorganic compounds, and their disappearance from the earth's surface. This opinion would be hardly worth mentioning, were it not that it has furnished a foundation for entirely fallacious ideas concerning the essence of the vital processes in general, and especially of many pathological conditions, and the causes of certain diseases.

These philosophers regard fermentation, or the resolution of higher or more complex organic vegetable atoms into less complex compounds, as the effect of the vital manifestations of vegetable matters; and putrefaction, or the same change in animal substances, as being determined by the development or the presence of animal beings. They assume as a natural consequence of this view, that the origin of miasmic or contagious diseases, in so far as referable to the presence of putrefactive processes, must be ascribed to the same or similar causes.

The most obvious and important considerations in support of this view of fermentation are derived from observations made on the alcoholic fermentation, and on the yeast of beer and of wine. The microscopic researches of physiologists and botanists have demonstrated that beer or wine yeast consists of single globules, often strung together, which possess all the properties of living vegetable cells, and resemble very closely certain of the lower families of plants, such as some fungi and algæ. In fermenting vegetable juices, we observe, after a few days, small points, which grow from within outwards; and these have a granular nucleus, surrounded by a transparent envelope.

In agreement with these observations, chemical examination has proved, that the cell walls of the globules of beer yeast consist of a non-nitrogenous matter, having the composition of cellulose or woody fibre, which remains undissolved, when the yeast, after being well washed with water, is treated with weak caustic alkalies. The alkaline solution takes up a substance, which contains all the nitrogen of the yeast globules, and which, in chemical character and in composition, differs little, and that chiefly in the proportion of oxygen, from the gluten of grain. After incineration, yeast leaves an ash, entirely identical, in regard to its constituents, with the ash of the gluten of the cereals.

It has also been particularly pointed out, that in the fermenting beer-wort (infusion of malt), the formation and separation of the yeast cells keep pace with the production of carbonic acid and alcohol. When all the sugar is decomposed, no more yeast is formed. The yeast contains the nitrogenous constituent of the malt or barley, of which, when a certain amount of sugar is present, only traces are found in the liquid after fermentation.

The simultaneous appearance of the yeast cells, and of the products of decomposition of the sugar, is the chief argument in support of the opinion, that the fermentation of sugar is an effect caused by the vital process, a result of the development, growth, and propagation of these low vegetable structures.

If, by the term vital action, we understand the power of a germ or of a seed to take up certain substances from without, and to make them parts of itself; then the formation of the yeast cells in fermenting wort is, beyond all doubt, a proof of the existence of a vital action. The cell walls are, in all probability, formed at the expense of a certain portion of sugar, since they consist of a compound which stands higher in the organic scale than sugar, and never appears in a crystalline form. The contents of the cells have been derived from the gluten of the malt, and contain, among other things, parts, spores, or germs, which, if introduced into fresh wort, determine the formation and development of new cells.

But if the development increase, and propagation of these vegetable cells or tissues be the *cause* of fermentation, then, in every case where we observe this effect, we must suppose that the causes or conditions, namely, sugar, from which the cell walls are produced, and gluten, which yields their contents, are both present.

Now the most remarkable fact among the phenomena of fermentation, and that which must chiefly be kept in view in the explanation of the process, is this: that the ready-formed cells, after being washed, effect the conversion of pure cane-sugar into grape-sugar, and its resolution into a volume of carbonic acid and a volume of the vapour of alcohol, and that the elements of the sugar are obtained without any loss in these new forms; that, consequently, since 3 lbs. of yeast, considered in the dry state, decompose 2 cwt. of sugar, a very powerful action takes place, without any notable consumption of matter for the vital purpose of forming cells. If the property of exciting fermentation depended on the development, propagation, and increase of yeast cells, these cells would be incapable of causing fermentation in pure solution of sugar, in which the other conditions necessary for the manifestation of the vital properties, and especially the nitrogenous matters necessary for the production of the contents of the cells, are absent.

Experiment has proved, that in this case the yeast cells cause fermentation, not because they propagate their kind, but in consequence of the decomposition of their nitrogenous contents, which are resolved into ammonia and other products; that is, in consequence of a decomposition which is exactly the opposite of an organic formative process. The yeast, when brought into contact successively with new portions of sugar, loses, by degrees, entirely its power of causing fermentation, and at last nothing is left in the liquid but its non-nitrogenous envelopes or cell walls.

Hence it follows, that the cause of the resolution of the sugar into new forms cannot properly be sought for in a process of vegetation, because this effect takes place without the yeast cells being reproduced as a vegetable tissue, and under circumstances which destroy their power of propagation and increase. It is obvious, that the phenomenon depends on the presence of an action, or a state of change, which continues even when the conditions necessary to the formation of cells are excluded.

Further, if we consider that the action of yeast is not confined to sugar alone; that other bodies, of totally different composition, undergo a similar decomposition in contact with yeast; that tannic acid in a fermenting saccharine liquid passes into gallic acid; the malic acid of malate of lime into succinic acid, acetic acid, and carbonic acid; that an animal membrane, or the albuminous part of sweet almonds, (substances differing in composition from gluten,) when putrescent, produce the same changes as yeast: it follows, that the peculiar action of yeast depends on a more general cause, and not on the sugar; and that the resolution of sugar into alcohol and carbonic acid does not depend on a constant quality in the yeast.

Observation shows, that beer yeast, left to itself, very quickly loses its power of exciting the alcoholic fermentation. That power is lost when the yeast is rubbed on a levigating stone till all organic structure is destroyed; but this does not annihilate its power of decomposing organic substances in general. For it now acquires the property of converting sugar into lactic acid, and the lactic acid of lactate of lime into butyric acid, mannite, hydrogen, and carbonic acid. And these are effects which take place without any formation of cells or vegetable tissues.

All this proves that it is neither the organic form, nor the chemical composition of the yeast, but merely a certain state of the nitrogenous contents of the yeast cells, which must be regarded as the cause of the decomposition of sugar in the alcoholic fermentation.

The fermentation of grape-juice and of beer-wort is no isolated phenomenon; these are individual cases out of a class including many others. The alcoholic fermentation, in so far as it is accompanied by the formation or decomposition of fungi, is distinguished from other kinds of fermentation, in which no vegetable tissues are observed, in this, that the products of the decomposition of gluten possess, in addition to their chemical properties, certain vital properties. Gluten, vegetable albumen, and the vegetable caseine of

may show that fermen[illegible]
[illegible] is a different phenomenon

vegetable juices, cause fermentation, because they enter into decomposition; their action depends on the state of change of form and quality of their elementary molecules. As they gradually change and are separated, they assume, in consequence of other secondary causes, the forms of a low vegetable tissue, the vital properties of which depend on a transition state, and disappear on its completion or termination. The yeast cell, as a fungus or alga, has no independent existence.

As a single or individual case, the fermentation of sugar requires no special explanation, since no other expression can be given to the process than that developed in the preceding letters. The sugar is resolved into alcohol and carbonic acid in consequence of a disturbance of the equilibrium in the attractions of its elements, and this disturbance is caused by a substance whose elementary particles are in a state of motion.

Of the known processes of fermentation, only the alcoholic fermentation has been hitherto studied with any degree of accuracy; and we have observations (those of Doepping, Struve, and Karsten,) which prove that sugar may be resolved into alcohol and carbonic acid without the appearance of the fungi alluded to. In many other fermentations the constant occurrence of such vegetable tissues has not been observed. There is not the remotest proof of a real connection between the vital properties of these fungi and the formation of the products of fermentation; and no one has even attempted to connect the two phenomena as cause and effect, and to explain how or in what manner a plant can cause the resolution of sugar into alcohol and carbonic acid. When we examine strictly the arguments by which this vital theory of fermentation is supported and defended, we feel ourselves carried back to the infancy of science. There was a time when men could not account for the origin of the lime of the bones, the phosphoric acid in them and in the brain, the iron in the blood, and the alkalies in plants; and we now find it inconceivable that this ignorance should have been regarded, as it was, as a proof that the animal or vegetable organism possessed the power of creating iron, phosphorus, lime, and potash, by virtue of its inherent vital forces, out of food containing none of these substances. This convenient explanation naturally put an end to the inquiry as to their real origin, and arrested true investigation.

Simple observation leads, in the examination of certain fermentative or putrefactive processes, to the fact of the presence of organised living beings, and without asking any further questions, the presence of these fungi, whose origin is perfectly unknown, is connected with the formation of the products of fermentation and putrefaction, as their cause. Because no other cause can be found (or rather, because no other cause has been sought for by the observers of the fact,) which explains the formation of these products, we are desired to ascribe it to a cause which is utterly incomprehensible.

With respect to that theory which regards the putrefaction of animal matters as produced by microscopic animalculæ, it may be compared with the idea entertained by a child, who explains the rapid fall and current of the Rhine through the numerous Rhine mills at Mayence, by supposing that the mill-wheels, by their force, urge the water downwards towards Bingen.

Is it conceivable that the annihilation and destruction of plants and animals should be the effects of the agency of other plants and animals, which are themselves subject to the same processes of destruction?

If the fungus or mushroom be the *cause* of the destruction of the oak—if the animalcule be the *cause* of the putrefaction of a dead elephant; what then is the cause of putrefaction, after death, of the fungus? what is the cause of the putrefaction and decay of the dead animalcule? They also ferment, decay, and putrefy, and finally disappear entirely, just as do the mighty tree and the gigantic animal; and the final products are the same in all.

It is impossible to adopt this opinion, when we reflect, that the presence of microscopic animals in putrescent substances is quite accidental; that their appearance, in most cases, may be prevented by the exclusion of light; that putrefaction and decay may go on without the least assistance from them; that in a thousand cases, in putrescent wine, cheese, bile, or blood, no such animals whatever are observed; and that in other cases, they appear for the first time, in a certain stage, long after fermentation has begun.

To ascribe putrefaction to the presence of animalculæ is as irrational as it would be to ascribe to the beetles whose food is derived from animal excreta, or to the mites in cheese, the state of decomposition of the excreta or of the cheese.

The presence of animalculæ, which are often found in prodigious numbers in putrefying matters, cannot in itself be considered wonderful, since these animals find there the conditions of their nutrition and development combined.

Their appearance is not more extraordinary than the migration of salmon from the sea into rivers, or the growth of salt-plants in the vicinity of salt-works; the only difference lies in our ability to trace the latter in their progress; whilst the germs of the fungi, and the eggs of infusorial animalculæ, in consequence of their extreme minuteness, and the ocean of atmosphere through which they are diffused, must make their appearance everywhere, when no obstacle opposes the development of their germs or eggs.

It is quite certain that in their presence putrefaction is exceedingly accelerated. Their nutrition presupposes the consumption of particles of the animal body for their own development. Its more rapid destruction must be the necessary consequence. We know that one single individual procreates many thousands in a very short time, but their growth and development are confined within definite limits; when they have once reached a certain size, they no longer increase in bulk, whilst they continue at the same time to partake of nutriment. Then what becomes, we must ask, of the food which no longer augments their size? Must it not undergo in their organism a similar alteration to that which a piece of meat or bone undergoes in the body of a full-grown dog, the weight of which no longer increases? We know positively that the food of the dog serves for the support of the vital processes, and that its elements receive in its organism the form of carbonic acid and urea; which latter substance becomes resolved, after being eliminated from the organism, into carbonic acid and ammonia. This food, therefore, undergoes in the body the same alteration as if it had been burned in a stove; that is, it is subjected to eremacausis, or decay.

The same occurs in decaying animal substances; they serve as nourishment for microscopic animalculæ, in the bodies of which their elements decay. These animalculæ die when their means of subsistence are exhausted, and their bodies putrefy and decay, and, perhaps, serve for the nourishment and development of other races of living beings. But the process is, and continues to be, one of combustion, in which the elements of the original body, before combining with oxygen, became parts of living beings, in which, therefore, they form a series of intermediate compounds before they pass into the ultimate products of the process of decay. But the constituents of animals which enter into combination with oxygen in the organism no longer belong to the living body. During the true putrefactive process, that is, the decomposition of animal substances with the exclusion of oxygen, gases are evolved (sulphuretted hydrogen, for instance), which exercise a deleterious influence, and speedily put a limit to the life of even the microscopic animalculæ. The excrements of man, while putrefying, never exhibit the presence of microscopic animalculæ, whilst we find abundance of them in these excrements when in a state of decay. A wise arrangement of nature has assigned to the infusoria the dead bodies of higher orders of beings for their nourishment, and has in these animalculæ created a means of limiting, to the shortest possible period, the deleterious influence which the products of dissolution and decay exercise upon the life of the higher classes of animals. The recent discoveries which have been made respecting these creatures are so extraordinary and so admirable, that they deserve to be made universally known.

Count Rumford observed that cotton, silk, wool, and other organic substances, when exposed to the light of the sun under water, after the lapse of from three to four days gave rise to the evolution of pure oxygen gas. With the appearance of the first gas-bubbles the water assumes a greenish colour, and exhibits under the microscope the presence of an immense number of minute spherical animals, to which the green hue of the water is owing. No confervæ or other microscopic plants, to which the evolution of oxygen could be ascribed, were perceived.

These observations, made about seventy years ago, have been rescued from oblivion by recent observations.

In the salt-pans of the salt-works of Rodenberg, in the electorate of Hesse, a slimy and transparent mass is formed, which covers the bottom to the depth of from one to two inches, and is everywhere interspersed with large air-bubbles, which ascend in great numbers through the supernatant fluid, when the pellicles enclosing them are torn by agitating the mass with a stick. Pfankuch upon investigation found the air enclosed in these bubbles to be such pure oxygen that a wood splinter, the flame of which has been just extinguished, rekindles into a flame when immersed in it. This observation has been confirmed by Wöhler. The microscopic investigation of the mass at the bottom of the pans proved that it consisted of living infusoria, chiefly of the species navicula and gallionella, such as occur in the siliceous fossil strata of Franzensbad, and in the paper-like formations of Friberg. After being washed and dried, the mass, upon heating, evolved ammonia, and upon incineration left white ashes, consisting of the siliceous skeletons of these animalculæ, which preserved the original form of the animal so perfectly, that they looked like the original deposit only deprived of motion. About the same time, Messrs. Ch. and A. Worren, in the "Transactions of the Academy of Brussels" (1841), showed that water, with the co-operation of organic matters, evolves a gas containing as much as 61 per cent. of oxygen; and that this phenomenon is to be ascribed to the presence of *glamidomonas pulvisculus* (Ehrenberg), and some other green and red animalculæ belonging to a still lower grade in creation. I myself took an opportunity of verifying this remarkable fact, upon finding, in a trough of water in my garden, the fluid coloured green by the presence of various species of infusoria. I filtered it through a very fine sieve, in order to separate all confervæ or vegetable matters, and then exposed it to the light of the sun in an inverted beaker glass completely full, the aperture of which was confined by water. After the lapse of a fortnight, more than thirty cubic inches of gas had collected in the glass, which proved to be so rich in oxygen, that a glowing splinter at once burst into flame in it.

Without venturing to draw any inference from these data with respect to the mode of nutrition of these creatures, it is certain that the water in which infusoria exist, under the influence of the solar light, contains a source of pure vital air; it is certain that, from the moment these animals are perceived in the water, this water ceases to act injuriously upon the higher orders of plants and animals; for it is impossible to conceive that water should evolve pure oxygen, while it contains putrefying or decaying substances—that is, matters which are capable of combining with oxygen.

Now, if we suppose some animal matter in a state of putrefaction or decay added to water of this kind, this matter must, of course, be resolved into its ultimate products, in the presence of such a source of oxygen, in an infinitely shorter space of time than would be the case were these infusoria not present.

In the most extensively diffused animalculæ, namely, the green and red infusoria, we recognise a most admirable cause which removes from water all substances injurious to the life of the higher classes of animals, and creates in their place nutritive matters for the sustenance of plants, and the oxygen indispensable to the respiration of animals.

The infusorial animalculæ cannot be the causes of putrefaction,—of the production of poisonous matter deleterious to plants and animals,—but an INFINITELY WISE INTENTION designs them to accelerate the transition of the elements of putrefying substances into their ultimate products.

Among the fungi and agarics there are many species which develope themselves without light, and their growth and development are attended with all the circumstances characteristic of animal life. They contaminate the air and render it unfit for respiration, by absorbing oxygen and exhaling carbonic acid: in a chemical point of view, they are like animals without the power of motion.

In contradistinction to this class of beings, which can scarcely be called plants, there exist living beings endowed with motion and provided with the characteristic organs of animals, which act in the light like green plants; they, whilst multiplying in numbers and increasing in size, create sources of oxygen, and carry it with them wherever the access of oxygen in the form of air is impeded or altogether precluded.

It is evident that infusorial animalculæ can make their appearance, develope, and multiply, only in those places where they find an abundance of the necessary nourishment in a form adapted to assimilation. Several species, and these very widely diffused infusoria, are distinguished from other species by possessing certain inorganic constituents, namely, silica, which forms the shells, or cuirasses, as they may be termed, of *naviculæ*, *exilaria*, *bacillaria*, &c., and peroxide of iron, which is a constituent of many *gallionellæ*. The carbonate of lime of the chalk animalculæ is precisely similar to the shells of the common molluscous animals.

Many persons have pleased themselves with ascribing the enormous depositions of silica, of lime, and of peroxide of iron in the siliceous fossil strata, in emery, in tripoli, in chalk, and in bog ores, to the vital process of primeval infusoria; as if the formation of these enormous geological strata could be effected solely by the vital principle! But they have altogether overlooked the circumstance that chalk, silica, and peroxide of iron must first be present as the necessary conditions of the life of these creatures before they could be developed; and that those constituents at the present moment are never absent from the sea, the lakes, the marshes, where the same forms of animalculæ occur in a living state.

The water in which these primeval infusoria lived contained the silica and the chalk in solution, and in a condition perfectly suitable for their deposition in the form of marble, quartz, and other similar mineral masses; and this deposition would have taken place inevitably in the ordinary manner, if the water had not contained the putrefying and decaying remains of preceding races of animals, and in them the other conditions of the life of siliceous and calcareous infusoria.

Without a combination of these circumstances—the presence of these substances constituting the conditions of their existence—none of these species of animalculæ would have propagated and increased to form these enormous masses. These infusorial animalculæ can only be considered accidental media of the form which the minute particles of these depositions exhibit—accidental, inasmuch as even without these creatures, deposition of the silica, the lime, the peroxide of iron, would have taken place. Sea-water contains the lime of the coral animals, of the innumerable mollusks existing in this medium, in the same form and condition as it is contained in lakes and in marshes, in which the chalk animalculæ develope themselves, or those mollusks the shells of which constitute the muschelkalk formations.

The adherents of the theory according to which putrefaction is caused by infusoria and fungi, regard a putrescent body as a nursery of infusoria or a plantation of fungi; and where organic matters putrefy over large surfaces, the whole atmosphere must be filled with the germs of these organised beings. These germs, in so far as they develope themselves in the bodies of men and animals, are, according to these philosophers, the germs of disease, and the essence of contagions and miasms.

The foundation of this parasitic theory may be reduced to two facts: one is the propagation of scabies; the other, a disease which occurs in the silkworm, the muscardine.

Scabies, or the itch, is an inflammation of the skin, caused by a mite (*Acarus Scabiei, Sarcoptes humanus,*) which lives in the skin, or, more properly, in its pores. In order to the communication of the disease, a continued approach, especially during the night, of the healthy to the infected person, is necessary, because the *Acarus Scabiei* is a nocturnal animal of prey. That the insect is really the contagion of scabies, is proved by the following facts : inoculation with the matter of the pustules does not excite scabies ; neither does inoculation with the crusts of these pustules ; the itch can be cured by rubbing with brick-dust ; and it cannot be communicated by male *Acari*, but only by the impregnated female insect. The disease spreads over the surface by propagation of the animal ; it is chronic, and does not heal spontaneously.—(HENLE.)

The contagion is, therefore, an animal with a masticatory apparatus, which lays eggs. It is a fixed contagion, because the animal cannot fly, and because its eggs cannot be carried through the air.

The muscardine is a disease of the silkworm, caused by a fungus. The germs of this fungus, introduced into the body of the worm, grow from within at its expense. After the death of the animal, they penetrate the skin, and on the surface appears a grove of fungi, which gradually dry into a fine dust, which, on the slightest agitation, rises from the substance on which it lies, and is diffused in the air. It is the type of volatile contagions. Good nourishment and perfect health increase the liability to infection in the individual worms to which these germs are conveyed.

But it has been observed, that a number of insects develope and propagate themselves only in the body or under the skin of higher animals, the disease and death of which is often produced by them. If we call the *Acarus Scabiei* a contagion, then all diseases caused by animals or parasites in the same way are contagions, since the size of the parasite can make no difference in the explanation.

There are parasitic plants, like the muscardine, found in diseased fishes, in infusoria, in hens' eggs.

and it is therefore certain that these observations establish a class of facts very frequently met with in the animal and vegetable kingdoms; namely, disease and death caused by parasites, which live exclusively at the expense of the bodies of other plants or animals; and if it is right to call a fungus a contagion, it must be admitted, since the size cannot affect the nature of the phenomenon, that there are contagia six or eight inches long; for the *Sphæria Roberti*, which is developed in the body of the New Zealand caterpillar, attains that bulk.

When, however, we know that scabies is propagated by an animal, and other diseases by fungi, no special theory is required to explain infection in such cases; and it is obvious that all states belong to the same class, in which we can detect the same or similar causes of their propagation.

But, if we inquire what are the results of investigation, or of the search after such causes in other contagious diseases, we find, that in the contagion of small-pox, of plague, of syphilis, of scarlet-fever, of measles, of typhus, of yellow fever, of hospital gangrene, and of hydrophobia, the most conscientious observation has not been able to discover animals or any kind of organised beings, to which the propagation of the diseases can be ascribed.

There are, consequently, diseases caused by animals, by parasites, which grow in the body of other animals, and at the expense of their constituents. These cannot be confounded with other diseases in which such causes are entirely absent, whatever be the external resemblance between them. It is possible that, in one contagious disease or another, further research may show that they belong to the class of diseases caused by parasites; but so long as this is not proved, they must, by the rules of scientific investigation, be excluded from that class. The scientific problem is, to discover the special causes of these other diseases.

The question, if properly put, will lead us to the path by following which the answer is to be obtained.

The greatest difficulty in such investigations is, obviously, that, when we have reached a certain point, we can no longer distinguish the effects of the vital forces residing in a living being from those of physical forces. All attempts to define strictly the line which separates animals from plants, to discover certain or infallible marks of distinction between them, have hitherto been unsuccessful. What we perceive are transitions, but not boundaries. There are actions, caused by physical forces, which exhibit many of the peculiarities of vital actions. In an animal of a high class we observe, in the arrangement of its parts, and in the wonderful agencies derived from these, so great and marked a difference, when compared with the phenomena of inanimate nature, that many are led to ascribe them to peculiar causes, quite different from inorganic forces. The vital phenomena, and their unknown cause, long appeared to naturalists so predominant, that the co-operation of physical and chemical forces was forgotten; their presence was contested and denied. In contrast to this, in the lowest orders of plants, chemical and physical agencies so preponderated, that special proofs of the existence of vital forces became necessary. There are living beings which in their form resemble inorganic precipitates. It is a fact, that experienced observers have taken crystalline deposits for *Algæ* or *Fungi*, and have thus described them. At the boundary line, the effects of chemical forces are no longer distinguishable from those of the vital force.

It is truly marvellous that the power active in animal organisms, the vital force, should be able to form, out of only four elements, a number of compounds, infinite even in the mathematical sense of the term; that by it carbon, oxygen, hydrogen, and nitrogen, should be formed into substances possessing all the properties of metallic oxides, or of inorganic acids and salts; that upon the verge of what is termed inorganic nature, a series of organic elements begins, and becomes so extensive as to surpass the limits of our conception. We see the whole of inorganic nature, all the numerous combinations of the metals, reproduced in organic nature: with carbon and nitrogen, with carbon, hydrogen, and oxygen, with nitrogen and hydrogen, are formed compound atoms, which, in their properties, are perfectly analogous to chlorine, to oxygen, or to sulphur, or to a metallic body—not in a few isolated points of resemblance, but in all their properties. It is scarcely possible to imagine anything more wonderful than that carbon and nitrogen should form a gaseous compound (*cyanogen*), in which metals burn with the evolution of light and heat, as in oxygen gas; a compound substance which, in its properties and deportment, is a simple substance—an *element*, the smallest particles of which possess the same form as those of chlorine, bromine, and iodine, since it replaces them in their combinations without any alteration in the crystalline form of the compound. It is in this, and in no other shape, that the living organism creates elements, metals—metalloids,—groups of atoms so arranged that the forces, active within them, acquire the power to manifest themselves in far more manifold and diverse directions than is the case with inorganic atoms. But there is no power in nature to produce substances out of itself, or out of nothing,—none capable of annihilating those causes which impart to matter its properties; iron never ceases to be iron, carbon never ceases to be carbon, nor hydrogen to be hydrogen. No iron, no sulphur, no phosphorus, can be created in the living organism. The opinions we have adverted to will be looked upon half a century hence with the same smile of compassion which we bestow upon the dreams and fancies of alchemy. It belongs to human nature to form such notions, to create such hypotheses, wherever the mind, as is the case in infancy, is too little developed to comprehend the truth.

The acquisition of the most common necessaries of life is ever the fruit alone of labour and of effort. It is the same with intellectual wealth—the knowledge necessary to increase and perfect our mental and moral powers, to obtain an insight into and an apprehension of all truth. There is *want* only where no firm WILL exists—where no adequate efforts are exerted. The necessary means and instruments exist abundantly everywhere.

LETTER XX.

THROUGH Nature herself, who is a whole, the natural sciences stand in a necessary mutual connection, so that no one of them can entirely dispense with all the others for its development. The extension of the individual branches of science by researches, has the inevitable result, that in a certain stage, or at a certain period, two of them, for example, come into contact at their boundaries. As a general rule, a new science arises on the debateable land between them, which combines in itself the objects and the modes of viewing the phenomena of both. In order to this interpenetration, both must have reached a certain advanced stage; the independence of the original territories must be secured, for till this be done, the energies of the philosopher will not be applied to the border province. In these days we look forward to such a fusion of physiology with chemistry, as to one of the most striking results of scientific investigation. Physiology has attained a point at which it can no longer dispense with chemistry in striving after its object, namely, the study of the vital phenomena in their natural succession. Chemistry, the duty of which is to show in what degree the vital properties depend on chemical forces, has been prepared, and is now ready, to take up new departments of science, to be independently studied.

The phenomena presented by animals during their life are among the most complicated natural appearances; and the detection of their different causes, and the ascertaining the precise share of each in the result, is a task of peculiar difficulty.

It is a rule in natural science to divide every difficulty, which is to be examined, into as many parts as possible, and to study each of these separately. According to this rule, all physiological phenomena may be divided into two classes, of which each, up to a certain point, may be studied quite independently of the other. Such a separation, it is obvious, is not found in Nature, where both classes of phenomena are mutually dependent, so that, indeed, they mutually determine each other.

The processes of impregnation, development, and growth in animals, the mutual relations of their organs, and the agencies peculiar to these,—the laws of their motion, and of that of the fluids of the body,—the anatomical and other peculiarities of nervous and of muscular fibres; all these striking and interesting phenomena may be ascertained without regard to the nature of the substances which form the parts in which these properties reside. But physiology has to do with other phenomena, not less important. Digestion, sanguification, nutrition, respiration, and secretion depend on a change of form and quality on the substances introduced from without into the system, or on certain solid or liquid constituents of the organism; and it is in the study of these processes, as far as they can be regarded apart from structure, that chemistry must come to the aid of physiology. It is evident that physiology has two foundations, and that by the fusion of physiological physics, the foundation of which is anatomy, with physiological chemistry, which rests on animal chemistry, a new science must arise, a true physiology, which will stand in the same relation to the physiology of the present day, as modern chemistry does to that of the eighteenth century.

In order to form a just idea of the interpenetration of physiology and chemistry, we must call to mind similar occurrences in the history of science. Thus the character of modern chemistry has been essentially determined by the circumstance that it has absorbed into itself entire branches of physics, which now no longer belong to that science. The density of bodies in the gaseous state, forty years ago, was regarded as a purely physical character; but since we have learned that this property depends on the composition in a fixed relation, the study of this property belongs to chemistry. Similar relations have been discovered between the specific heat, the boiling point, and the crystalline form of bodies, on the one hand, and their composition on the other; and it is now chemistry which especially occupies itself with the exact determination of these properties. The doctrine of electricity, so far as it is the result of a change in form and quality, of a chemical change, has now almost entirely passed into the domain of chemistry.

Exactly in the same way, the more accurate knowledge of vital phenomena will establish the conviction that a number of physiological properties depend on chemical composition; and physiology, when it shall have taken up animal chemistry as a part of itself, will possess the means of investigating this relation of dependence; it will then be enabled to find a juster expression for physiological phenomena.

Men have often tried to explain vital phenomena exclusively on chemical principles, and to make physiology a part of chemistry. This was done centuries ago, at a time when the chemical changes in the body were better known than the organism itself. But when men had learned to know the admirable structure, the form and quality of the organs, and their combined action by a more exact study of anatomy, they imagined that they had found the key in certain principles of mechanics. All such attempts have entirely failed; and their failure gave rise to physiology as an independent science. Mineralogy was in a similar relation to chemistry; forty years ago, many considered it a part of chemistry, and compound minerals were classed with the salts. Mineralogy conquered her independence, not by rejecting the doctrines of chemistry, but by taking into her own domain the determination of the composition of minerals. Since mineral analysis has become a part of mineralogy, it is from mineralogists that we have obtained, and daily obtain, the most valuable results in regard to the relation which exists between the chemical composition of minerals and their crystalline form and other physical properties.

One difficulty in effecting a mutual understanding, which, however, may easily be removed, still exists in the circumstance, that in physiology, the same word does not always imply the union of the same things or of the same compounds with the same properties; but that, in any such words, less attention is paid to the nature and quality of the substance than to the part ascribed to them on the vital process, or their occurrence in certain organs.

In physiology, for example, the words *urine* and *bile* are used to designate fluids, which are found in the sacs of certain organs, the nature of which may vary in many ways, without their ceasing to be regarded as urine or bile. In like manner, the physiological idea of blood is not derived from certain properties, but is attached, without any regard to form and colour, to the nutritive property, or the *nutritive function* of the fluid, and is inseparable from that idea, to which all other properties are made subordinate.

In chemistry, which studies the properties of bodies, the names of urine, bile, blood, milk, &c., are attached to the complex ideas of certain properties in each; in such a manner, that the name must not be given to a substance, when the properties included in it are wanting; and since all these fluids are mixtures of several less complex compounds, chemistry distinguishes those which are invariable or characteristic from such as vary and do not determine the leading properties.

The notion of urine is, in chemistry, inseparable from the presence of certain compounds, urea and uric acid; and, chemically, the name of urine cannot be given to a fluid, in which these are entirely absent.

Blood and milk are mixtures; the ingredients of which are present, not in fixed invariable proportions, but in variable quantities. The mixed quality of the blood is even visible to the naked eye. Under the microscope we see minute red discs, the blood globules, swimming in a colourless or pale yellow fluid, the serum, or rather liquor sanguinis. Lymph contains two colourless bodies, one of which coagulates spontaneously, as fibrine, at ordinary temperatures; the other is coagulated by heat, as albumen. Its turbid milky appearance is caused by suspended and visible drops of fat oil. When lymph is agitated with ether, it becomes clear, the fat being dissolved by the ether.

The mixed nature of some other fluids, as of the bile, is not so easily demonstrated; but still it may be easily done by the use of chemical means of separation, such as we know do not produce any real chemical change in the substances to which they are applied.

The bile of animals is golden yellow, green, or yellowish brown; when freshly taken from the gall-bladder, it contains a gelatinous, swelled-up, tasteless matter, insoluble in water, mixed with it, which is entirely separated by the addition of alcohol. The alcoholic solution has the colour of the bile; and if filtered through charcoal powder, the colouring matter is retained, while all the other constituents are found in the colourless solution.

Bile, then, is coloured as blood is; with this difference, that its colouring matter is dissolved, not suspended, although it is not in chemical combination with any of the other organic constituents. Were it so combined, the charcoal which retains it would also retain some other substance; but it contains none, save the colouring matter. When bile is shaken with ether, or when a sufficient quantity of ether is added to the colourless alcoholic solution, the mixture forms two strata; one a heavy syrupy liquid, which subsides, the other a lighter, which swims above it. The latter contains the ether, in which is found a quantity of fat. This fat was a constituent of the bile, not however suspended in drops as in lymph, but dissolved.

The bile of birds, mammalia, fishes, and amphibia, so far as yet examined, behaves as above described towards alcohol, charcoal, and ether. It is no single compound, but a mixture of several such compounds. Were it a single compound, no one of its properties could be removed without destroying all or the greater part of the rest. Now, from bile we can remove its viscidity, its colour, its soapy quality, without the slightest change in the other essential properties;

but from the matter which is left, the purified bile, we cannot remove any one of its properties without destroying it. It is, then, a compound, or rather two compounds, of soda with two acids (formed by the coupling of the nitrogenised bodies, glycocoll [sugar of gelatine], and taurine, with the non-nitrogenised cholalic acid), and distinguished by its very bitter taste, and by the property of assuming a purple red colour when acted on by sugar and concentrated sulphuric acid.*

The observation, that almost all parts of the animal body, the substance of the nerves and brain, and the fæces, contain the same kind of fat as the bile ; that the serum of coagulated blood has a colour very similar to that of bile ; that the mucus which forms on the surface of the intestinal canal is not distinguishable from the mucus of the gall-bladder : all this shows, that fat, colouring matter, and mucus are not to be considered as essential or peculiar to the bile ; whereas the bitter substance, insoluble in ether, soluble in water and alcohol, is found in the healthy state only in the bile, and in no other part of the body. It is, therefore, regarded by the chemist as that which gives to the bile its character, so that, in a chemical sense, bile means only this one constituent.

For the same reason, uric acid, urea, and allantoine, which are allied compounds, inasmuch as uric acid may be converted into urea and allantoine, are regarded as the characteristic constituents of the urine of all animals, because every urine contains two or one of them. Hippuric and benzoic acids, which are constituents of human urine, as well as of that of the horse and cow ; and kreatine and kreatinine in human urine, are variable, not essential constituents,

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* It is remarkable that the bile of the swine contains a peculiar organic acid, analogous to, but distinct from, the acids of all other kinds of bile yet examined.

because they do not occur in the urine of birds and serpents, or at least have not been detected therein.

It is well known that fresh-drawn blood, if left to itself, in a very short time coagulates to a gelatinous mass, and that this coagulation depends on a separation of the fibrine of the blood, which separates from the fluid (the serum) in the form of a jelly, or rather a network of infinitely fine colourless translucent fibres, which inclose the red globules, and thus form the clot. If the blood, before coagulation, be whipped or beaten with a rod or bundle of twigs, no clot is formed, because the fibrine is prevented from forming a network; the fibres adhere into coarser elastic white masses, which, when washed with pure water, lose all red colour, and become perfectly white. This fibrine, if laid in water, to every ounce of which a drop of muriatic acid has been added, swells up to a stiff jelly, without dissolving;* when the quantity of water is not too large, it is absorbed by the swollen fibrine as by a sponge; and if concentrated muriatic acid be added to the mass, the fibrine shrinks to its original bulk. If again laid in water, it again swells up, and shrinks again on the addition of acid. After the fibrine has been thus treated alternately for ten times, it leaves, when dried and incinerated, 2 per cent. of ash, containing peroxide of iron, lime, and phosphoric acid. It is perfectly obvious that these substances were not merely mixed with the fibrine; for they are retained by it with a force much greater than the strong affinity of muriatic acid for phosphate of lime and oxide of iron. These inorganic substances are, therefore, considered as essential and necessary constituents of the fibrine of blood.

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* In these properties the fibrine of blood is very different from that of muscle, a chief constituent of the animal body; which, under the same circumstances, dissolves into a clear liquid, only troubled by drops of fat suspended in it.

This want of mutual understanding in the terms used is not the only obstacle to the vigorous co-operation of chemistry and physiology. A still greater difficulty lies in the difference of their methods of research.. In the investigations of chemistry and physics, it is a principle, that a composite phenomenon must, above all things, be reduced, by observation, to more simple facts. We then begin with the simple, and pass on to the study of the complex. The first questions refer to the proximate, not to the ultimate causes, and we proceed from the known to the unknown. In physiology and pathology, men long tried to investigate the most complex phenomena before they were acquainted with the simplest. They attempted to explain fever before they knew anything of respiration; they explained the development of heat in the body, without taking into account the influence of the atmosphere; and the function of bile in digestion was explained before the composition of the bile was known. Hence the perpetual strife concerning the causes of life, which in itself is so little edifying, so purposeless, so profitless, because the proximate causes of the simplest vital phenomena are hardly known to us.

It is certain that a number of effects, observed in the living body, are determined by chemico-physical causes, but it is going much too far to conclude from this that all the forces which act in the organism are identified with those which govern dead matter. It is easy to show that those who adopt such an opinion have lost sight of the first and simplest rule of the physico-chemical method of inquiry, which directs us to prove that an effect which we ascribe to a cause really is due to that cause, and no other.

If heat, electricity, magnetism, and chemical attraction, are to be viewed as the causes of vital phenomena, we must first of all prove that those parts of the animal body, in which forces act, exhibit phenomena similar to those observed in inorganic bodies, when subjected to the action of the same forces. We must show how the physical forces, above named, act together to produce the admirable harmony of arrangements presented by organised beings from their first development to the period at which their elements are again restored to the domain of inorganic nature. For if we suppose that the forces of inorganic nature are identical with those of organic nature, we necessarily assume that all natural forces are known to us; that their effects are ascertained; and that we are able to deduce the causes from the effects, and to explain the share which belongs to each in the arrangements which constitute life.

It suffices to cast a glance at the writings of the authors who defend this view, in order to perceive how far we still are from any such conclusion. This opinion generally proceeds from very able and profound philosophers, who have attended exclusively to the phenomena of motion in the animal organism. Finding that these phenomena occur according to fixed mechanical laws, they are tempted to believe that they are determined by the same laws as the similar phenomena observed out of the body. But no one has hitherto ventured to point out the relations of these effects to heat, electricity, magnetic force, &c., or to show the degree in which they are dependent on these forces. All that we know of the matter is, that the inorganic forces have a certain share in these effects.

On the other hand, it is quite impossible to partake the opinions of those who believe that they can explain the mysterious phenomena of life by the assumption of one or more vital forces. These persons take a phenomena, without inquiring whether it be simple or complex. They ask, whether it can be explained by chemical affinity, or by the electric or magnetic force; and since, at this time, it is impossible to answer this question in the affirmative, that is, as a matter of undoubted proof, they conclude that the phenomenon is determined by none of these forces, but by very peculiar forces belonging to living beings. But, in the search after the causes of phenomena, the method of exclusion is only permitted in those cases in which we are certain that the total number of causes to which the effect can by possibility be referred, is positively known and fixed; and then only on condition of proving that the effects belong to one alone of all these causes.

The physical forces, as far as concerns their nature and essence, are very little known; and no one can maintain that any one of them has no action in a given case, that it has no share in any given vital phenomenon. We have detected the most wonderful connections between the electric force and chemical attraction, but we are still far removed from knowing with certainty the real nature of these relations. Cohesion, or the cause of the grouping of homogeneous or like atoms into a mass, is known to us in its essence least of all; and its relations to chemical attraction, to that which groups dissimilar atoms, are yet more obscure than those of the latter to the electric forces.

Affinity, or chemical attraction, is to us, at this moment, the cause to which we ascribe, immediately, the combination of unlike atoms; but the mutual attraction of the same bodies is not invariable, it does not always remain the same, and it is impossible for us to consider the force by itself, precisely because it never acts alone, and because, in order rightly to appreciate one of its effects, we are compelled to attend to those circumstances,—temperature, cohesion, electrical state, &c., in which bodies are found, when we cause them to act on each other.

We have recently become acquainted with a large number of phenomena, of which we hardly know which of all the known forces or causes have a share in producing them. In former ages, men would have hastened to deduce from this the existence of peculiar forces till then unknown. This we no longer do, because we are conscious of our ignorance in reference to the peculiarities of the known forces, especially of the so-called molecular forces, cohesion and affinity.

If we place in a common champagne glass a solution, saturated at a high temperature, of Glauber's salt in water (two parts of the salt to one of water), and allow it to cool, the salt crystallises, and the liquid congeals to a thick mass of crystals, like ice. If the same glass be half filled with the hot solution, its mouth covered with a plate of glass, a watch-glass, or a card, and then allowed to cool, the liquid, after ten hours, or more, deposits no crystals, not even when the covering is removed. If we now immerse in it a common glass rod, the most beautiful needles and plates of Glauber's salt, are formed from the surface of the rod, and in a few seconds the congelation is complete. The liquid is in a glass vessel, but, although in contact with glass, does not crystallise; another portion of glass, that had not cooled with it, instantly causes crystallisation. This appearance is sufficiently remarkable; but still more striking is the fact, that if we heat one end of the same glass-rod for a few minutes in the flame of a spirit-lamp, and then allow it to cool, the rod, at that end, is quite without action on the crystallisation of the salt. It may be immersed in the liquid, and moved about in it, without causing the slightest change. But if we turn the rod round, and touch the liquid with the other end, which has not been heated, crystallisation at once ensues. To a superficial observation, the rod seems as if it now had poles, like a bar-magnet. At one end it retains a property, which it has lost, by the action of heat, at the other. If left exposed to free air, it gradually recovers the lost power; but if enclosed in a shut vessel, it continues inactive on the solution for ten or fourteen days. Even after being dipped in water, and allowed to dry in the air, it has not recovered its lost efficacy.

We have a sufficient explanation of the effect of motion on crystallisation ; but the action of heat on the property possessed by the glass-rod, of causing crystallisation, is, up to this time, utterly unexplained and obscure.

If we place a copper-plate engraving on the top of a shallow open pasteboard box, on the bottom of which lies a little iodine, and thus expose it for a few minutes to the vapours of iodine, such as rise at ordinary temperatures, and if we then press it firmly on a sheet of paper, which, like machine-made paper, has been sized with starch jelly, and is moistened with very diluted sulphuric acid, we obtain, on this paper, a most exact impression of the engraving in the most beautiful azure blue. If this blue impression be laid on a polished copper-plate, the blue lines gradually disappear, and the image now appears in perfect distinctness on the copper. A copper-plate, a drawing, even an oil-painting, when exposed for a short time to the iodine vapours, are reproduced on a plate of silver, and when this plate is now exposed, as in the daguerreotype, to the vapour of mercury, and treated in the usual way, a beautiful daguerreotype picture is obtained, but without the aid of light. It is here quite obvious, that the dark parts of the copper-plate, or of the drawing, have attracted and condensed the vapour of iodine in a much higher degree than the white paper. A moist surface, containing starch jelly, attracts the iodine from the dark parts ; on the paper appears the blue iodide of starch, as a blue copy of the engraving. A plate of copper, again, attracts the iodine from the blue compound, and on the copper appears a copy in iodide of copper.

It is evident that the white paper, the black colour or ink, the starch and the copper, have very unequal attractions for the iodine ; and that the cause of the condensation of the iodine is identical with that which effects the condensation of gases in general on the surface of solid bodies. The ink of the engraving attracts the iodine, but no true chemical compound has been formed; for the properties of the black colour remain unchanged, and the iodine of its properties has only had its volatility destroyed or diminished; it acts on starch like free iodine.

By these phenomena, we are involuntarily reminded of one of the most remarkable occurrences in the animal body, namely, the part played in the respiratory process by the solid parts or globules of the blood.

The blood owes its colour to these globules or corpuscles; and we see that these pass in the lungs from dark red to scarlet, while this change of colour is accompanied by an absorption of oxygen. The physiological phenomena, as well as the behaviour of the liquor sanguinis when separated from the globules, in contact with air and oxygen, teach us, that a great part of the oxygen which enters the blood is taken up by the blood corpuscles, which behave towards the gas as rough or coloured substances do towards the vapour or gas of iodine. The oxygen forms with them a compound of a peculiar kind; for it retains when absorbed or condensed, its chemical character, and its power of combining, in the course of the circulation, with other bodies for which it has an attraction.

We suppose that the attraction of the black ink of an engraving for iodine, and, as Niepce has shown, also for chlorine, and a number of other bodies in the form of gas or vapour, as well as that of the blood corpuscle for oxygen gas, is an effect of chemical attraction or affinity; but our notions of the essence of this force are as yet so limited, that we have not even a name for this kind of combination.

There are, as we see, phenomena enough which cannot be explained after the pattern of the usual notions, such as we have been taught; there are signs and proofs that we are still very far from knowing the laws even of known forces. We can resolve with a given quantity of sulphuric acid, unlimited quantities of alcohol into ether and water; we can, by the help of the same acid, convert a quantity of starch into grape-sugar, without the acid being neutralised in either case. These effects are utterly distinct from the effects produced when sulphuric acid acts on metals or on metallic oxides; but it is quite absurd to ascribe them to a peculiar cause, altogether different from chemical affinity. That which we commonly call a chemical action is a manifestation of chemical force, and is nothing more than a fact which proves, that in a given case, chemical attraction is more powerful than all the resistances which oppose its manifestations. But chemical combination is only ONE effect, and certainly it is not the only effect, of chemical affinity.

This imperfect state of our knowledge of the essence and of the effects of natural forces, explains how it comes to pass, that at this moment we are unable to solve the question in reference to the existence of a peculiar force or influence, acting in the living organism, by the method of exclusion or elimination.

LETTER XXI.

THE history of science gives us the consoling assurance, that we shall succeed, by pursuing the path of experiment and observation, in unveiling the mysteries of organic life, and that we shall be enabled to obtain decided definite answers to the question—What are the causes which have a share in producing the vital phenomena? All the peculiarities of bodies, all their properties, are determined by the co-operation of several causes; and it is a problem to be solved by scientific research, to ascertain the proportion in which each individual cause contributes to the effect. In order to attain a knowledge of the mutual relations of these properties, we must endeavour to become acquainted with them, and to discover the cases in which they vary. It is a natural law, which admits of no exception, that variations in one property are always and invariably accompanied by uniform and corresponding variations in another property, and it is perfectly obvious, that if we know the laws of these variations, we are enabled to deduce one property from the other without further observation.

To ascertain a natural law, is nothing more than to ascertain such a relation of dependence. Knowledge of the law includes explanations of the phenomenon, and an insight into the essence of the forces, by which it is determined.

It is known, that every liquid, under the same circumstances, boils at a fixed temperature. This is so constant, that we regard the boiling point as a characteristic property of liquids.

One of the conditions which determine the constant temperature, at which, in the interior of liquids, bubbles of vapour or gas are formed and rise unchanged, is the external pressure. The boiling point varies with the pressure in all liquids, in each according to a special law. It rises or falls, when the pressure is increased or diminished. A certain pressure corresponds, in any liquid, to each boiling point, and a certain boiling point to each pressure. The knowledge of this law of the dependence of boiling point on the atmospheric pressure, has led to a method of measuring elevation above the level of the sea; that is, to measure one property by the variations of another.

The relations in which the boiling point of liquids stands to their composition, are less generally known. Wood spirit, alcohol, and the oil of potato spirit are three liquids of very different boiling points. Wood spirit boils under the pressure of 30 inches of the barometer, at 59° C.; alcohol at 78° C.; potato oil at 135° C. The comparison of these three temperatures shows that the boiling point of alcohol is 19° C. higher than that of wood spirit (59° + 19 = 78°); while that of the oil of potato spirit is four times 19° higher than that of wood spirit (50° + [4 × 19] = 135°).

Each of these three liquids yields, by oxidation, under the same circumstances, a volatile acid; from wood spirit is obtained formic acid; from alcohol, acetic acid; from oil of potato spirit, valerianic acid. Of these three acids, each again has a constant boiling point; formic acid boiling at 99°; acetic acid at 118°; and valerianic acid at 175° C. On comparing these temperatures, we at once see that they bear to each other a relation similar to that observed between the boiling points of the original liquids. The boiling point of acetic acid is 19° higher than that of formic acid; and that of valerianic acid is four times 19° higher than that of formic acid. A uniform variation in one property corresponds, as we shall see, to a uniform variation in another property. One of the properties, in this case, is the composition.

If we compare the composition of the six bodies, the three alcohols, or original liquids, and the three acids formed from them by the action of oxygen, we obtain the following results. The composition of wood spirit is represented by the formula, $C_2 H_4 O_2$; that of alcohol, by $C_4 H_6 O_2$; that of the oil of potato spirit, by $C_{10} H_{12} O_2$.

If now we designate by R, a weight of carbon and hydrogen, corresponding to the symbol C H, that is, one equivalent of each, we see at once that the formula of alcohol is equal to that of wood spirit, + 2 R.

Wood spirit. Alcohol.

$$C_2 H_4 O_2 + C_2 H_2 = C_4 H_6 O_2$$

The formula of the oil of potato spirit (Amylalcohol), is equal to that of wood spirit, + 8 R.

Wood spirit. Amylalcohol.

$$C_2 H_4 O_2 + C_8 H_8 = C_{10} H_{12} O_2$$

The formula of the formic acid is $C_2 H_2 O_4$; that of acetic acid is $C_4 H_2 O_4$; that of valerianic acid is $C_{10} H_{10} O_4$. It is easy to see that the formula of acetic acid is equal to that of formic acid, + 2 R.

Formic acid. Acetic acid.

$$C_2 H_2 O_4 + C_2 H_2 = C_4 H_4 O_4$$

While that of valerianic acid is equal to that of formic acid, + 8 R.

Formic acid. Valerianic acid.

$$C_2 H_2 O_4 + C_8 H_8 = C_{10} H_{10} O_4$$

According to these facts, the entrance into such a compound, or the addition to its elements of two equivalents of carbon and two of hydrogen, or of 2 R, corresponds to a rise of 19° C, in the boiling point. It may be proved that this relation in the group above described is quite constant, and that from a knowledge of the boiling point, we may deduce, backwards, the composition of the liquid. The boiling point of the formiate of oxide of methyle (oxide of methyle is $C_2 H_3 O$, the ether of wood spirit), is 36° C; that of the formiate of oxyde of ethyle, (common ether, or oxide of ethyle, $C_4 H_5 O$) is 55° C. Here again, the difference is 19° C, while from this we might conclude that the composition of the latter formiate differs from that of the former by $C_2\ H_2$ or 2 R. This is found to be the case. The formula of formiate of oxide of methyle is $C_4\ H_4\ O_4$; and that of the corresponding compound of ethyle is $C_6\ H_6\ O_4$: therefore exactly increased by $C_2\ H_2$. Then, butyric acid boils at 156° O, a point exactly three times 19° higher than the boiling point of formic acid; and a comparison of the formula of the two shows that butyric acid may be regarded as formic acid + 6 R.

$$\underset{\text{Formic acid.}}{C_2\ H_2\ O_4} + C_6\ H_6 = \underset{\text{Butyric acid.}}{C_8\ H_8\ O_4}$$

Toluidine and Aniline are two volatile, organic bases, differing in composition so that Toluidine contains just $C_2\ H_2$ or 2 R more than Aniline; Aniline being represented by the formula $C_{12}\ H_7\ N$, Toluidine by $C_{14}\ H_9\ N$. Now, a comparison of their boiling points shows that Toluidine boils at a temperature 19° C. higher than the boiling point of Aniline.

In these examples it is impossible not to recognise the existence, for this group, of a natural law; no one can doubt that the qualities of a body stand in a definite relation to its composition; or that to a change in qualities, a uniform variation in something quantitative is found to correspond. It deserves here to be particularly noticed, that the knowledge of such a law of nature is quite independent of that of its proper or true cause, or of the conditions which, taken together, produce the constant boiling point; for what the boiling point of a liquid, considered in itself is, is a matter as little known to us as the true idea or definition of vitality.

In the above examples the relation between only one quality of bodies and their composition has been pointed out. But there are as many such relations as there are peculiar properties possessed by bodies. For a large group of organic chemical compounds a law has been made out, according to which, from the boiling point and the composition, we can determine the weight of a cubic foot of the compound; that is, the property of specific gravity, of the pressure which equal bulks of bodies exert on that on which they rest, is found to stand in a fixed relation to two other properties, and to vary as these vary.

A similar relation of dependence has been ascertained in regard to the amount of heat required by different bodies to cause in them an equal rise of temperature; and also in regard to the properties by weight in which they combine together, that is, their equivalent numbers.

It is a well-known fact that different bodies at the same temperature contain different quantities of heat. Equal weights of sulphur, iron, and lead, heated to the boiling point of water, cause, when placed in contact with ice, a certain quantity of it to melt; and the quantity of liquid water thus produced is very different in the three cases: the sulphur melting six-and-a-half times, the iron nearly four times, as much ice as the lead does.

Did these bodies contain equal amounts of heat, the weights of ice melted by all must be equal; and the inequality of effect is of itself enough to prove an inequality in the acting cause. It is perfectly certain, from experiment, that if we have to heat equal weights of sulphur, iron, and lead, to the same extent—say from 15° to 200° C.,—with the same spirit flame, we should require to burn, for a certain weight of lead, for example, one ounce of spirit; for the same weight of sulphur, six-and-a-half ounces; and for the iron, nearly four ounces of spirit.

The different quantities of heat thus required by equal weights of different bodies to undergo the same rise of temperature, which are peculiar to them, are called, precisely for this reason, specific heats. From a knowledge of the unequal quantities of heat contained in bodies of the same weight and at the same temperature, we can ascertain, by the rule of three, the unequal weights of sulphur, lead, and iron, which contain the same amount of heat; and it results from this calculation, that 16 parts by weight of sulphur melt as much ice as 28 of iron and 104 of lead. Now these numbers are the same which express their combining weights (equivalent numbers). Equivalents of these and of many other bodies take up equal quantities of heat in acquiring the same temperature; and if we regard the same equivalents as representing the relative weights of the atoms, it is clear that the amount of heat, taken up or given out by an atom, is equal for each atom, and when expressed in numbers for the atoms of different bodies, is in the inverse proportion of their equivalents or atomic weights.

It is certainly a very singular result that the quantity of ice melted by a warm body in cooling, has served in many cases to correct and to fix the weights in which that body combines with others.

But it will appear to many still more strange that this property of taking up or giving out heat, stands, in gaseous bodies, in quite a definite relation to the tone of a pipe or flute, produced by blowing with the gas in question; so that a distinguished philosopher (Dulong) was able to fix, from the unequal tones, the relative amount of heat which different gases give out on compression, or absorb on expansion.

In order clearly to understand this remarkable relation, we must call to mind one of the finest thoughts of La Place, in regard to the connection between the specific heat of gases and their power of propagating sound. It is well known that Newton, and many mathematicians after him, sought in vain for a formula which should express the velocity of sound in a manner corresponding to the results of observation. The calculated result was always near to the observed one; but an unaccountable difference always remained. Since the propagation of sound occurs by a vibration of the elastic gaseous particles, consequently as the result of a compression and a subsequent expansion of these; and since when a gas is compressed heat is given out, and when it again expands heat is absorbed, La Place conjectured that this heat might have an influence on the propagation of sound. It appeared, in fact, that after taking into account the specific heat of atmospheric air, the formula of the mathematicians became free from all error, and was an exact expression of the observed velocity.

If we now calculate the velocity of sound according to the formula of Newton, and therefore without regard to the specific heat of air, and if we compare the result with that derived from the formula of La Place, we perceive a difference in the length of the space traversed by a wave of sound in a second, in the two cases. This difference proceeds from the specific heat of air, from the amount of heat set free from the particles of air set in motion during the propagation of sound. It is plain that this difference in the velocity of propagation must be found greater or less in other gases, which for equal volumes contain, and, therefore, give out, more or less heat than air does; and it is easy to see how the numbers, which express the unequal velocities of propagation of sound in different gases, supply at the same time a measure for the unequal quantities of heat they contain, that is, for their specific heats.

Now since the acuteness or the gravity of tones depends on the number of vibrations of a sound-wave in a second—that is, on the velocity of propagation of the induced motion—and since we know that in all gases the velocity of propagation of the sound-wave is directly proportioned to the number of vibrations of the tones produced by it, we are thus able to explain how the specific heats of gases—that is, the unequal amounts of heat they contain—may be ascertained by the unequal acuteness of the tones they produce when forced through the same organ-pipe.

The great discovery that musical harmony, that every tone that melts the heart, attunes it to joy, or inspires it with valour, is the sign of a fixed and ascertainable number of vibrations in the particles of the propagating medium, and therefore a sign of all which, according to the doctrine of undulations, is deducible from that motion, has raised Acoustics to the rank which it now holds. Many truths regarding musical tones became deducible from the doctrine of undulation, while truths empirically obtained have led to a corresponding knowledge of the properties of vibrating bodies, formerly quite unknown.

It is said of the celebrated violin maker of Vienna, that he selected the wood for his violins in the forest with the aid of a hammer, and chose such trees as when struck yielded a certain tone, known to him alone. This is no doubt a fable; but not the slightest doubt can be entertained that he knew that the upper and under board of a good violin, make a certain number of vibrations in a second, that they give a peculiar tone, and that their thickness must be regulated accordingly.

Finally, if we reflect, that the electric current, passing through a wire of metal, stands in a fixed relation to the magnetic properties which the wire acquires; if we remember that the finest differences in radiant heat may be measured by the magnetic needle; that the amount of electricity set in motion may be expressed in numbers by the same needle, and may also be measured in cubic inches by hydrogen gas, and in weights of metal; when we see, that the causes or forces on which depend the properties of bodies, their power of acting on our senses, or, in general, of producing any effect—that these causes or forces stand to each other in an ascertainable relation of dependence,—who can any longer doubt that the vital properties of bodies, like all other properties, obey this law of dependence; that the chemical and physical properties of the elements, their form and mode of arrangement, play a definite and ascertainable part in the production of vital phenomena?

The mere knowledge of chemical formulæ is not sufficient. It is necessary to ascertain the laws of the relations in which the composition and form of the food, or of the secretions stand, to the nutritive process, or in which the composition of remedies stands to the effects which they produce on the system.

It is certain, that all the progress made by the physiology of plants and animals from the time of Aristotle to the present day, has only been rendered feasible by the progress of anatomy. Just as that man will remain in the dark concerning the manufacture of spirits, who sees no more of it than the mash, the fire, and the stop-cock from which the spirit drops, so, in truth, without an acquaintance with the apparatus, it is impossible to have an insight into the process. Now the organism, is a much more complex apparatus, which, before all else, requires an accurate knowledge of the structure of all the individual parts, before we can form a judgment concerning their value and their functions considered in reference to the whole organism.

But we must never forget that from Aristotle to Leuwenhoek, anatomy, by itself, has only shed a partial light on the laws of the vital phenomena; that, so to speak, the knowledge of the distilling apparatus does not teach us its object; that the same holds true of many organic processes, as of distillation, where he who knows the nature of fire, the laws of the diffusion of heat, those of vaporisation, the composition of the must, and that of the products of its distillation, knows infinitely more of distillation, not only than does he who is acquainted only with the minutest details of the apparatus, but also than does the coppersmith who made it.

With every new discovery on anatomy, our descriptions have gained in precision, accuracy, and comprehensiveness. The restless spirit of research has reached the cell, the foundation of organised structures; from this elevated point, a new investigation must begin.

If anatomical knowlege is to serve for the solution of a physiological question, something else must necessarily be joined with it; and the most obvious addition is that of the matter, of which the structure consists; of the forces and properties which, in addition to the vital ones, it possesses; a knowledge of the origin of the substance, and of the changes it must undergo in order to acquire vital properties. Finally, it is indispensable to the relations, in which all the constituents of the body, fluid as well as solid, independent of their form, stand to one another. To many physiologists, Chemistry alone appears enriched by what chemists have ascertained in regard to these all important questions; although these results, in Chemistry Proper, hold but a place as secondary as those which the analyses of minerals and of mineral waters have yielded.

From the erroneous notions entertained of the influence of chemistry on the explanation of vital phenomena, proceed the errors that, on the one hand, some estimate this influence too low, while some, on the other hand, raise their expectations from, and demands on it, too high.

When a decided relation between two facts exists, or is discovered, it is not the business of chemistry to prove this connection, but only to give it a quantitative expression to express it in numbers. By numbers alone no relation can be established between two facts, if such relation do not really exist.

Oil of bitter almonds and benzoic acid are two organic compounds, altogether distinct in their mode of occurrence and their properties. A few years ago, a mutual relation between them was not even suspected. But it was discovered, that the volatile oil, exposed to the air became solid and crystalline, and that the new body was identical in properties and composition with benzoic acid. It was now certain that a relation subsisted between them. Observation proved, that in the conversion of the oil into the acid, oxygen was absorbed from the air, and analysis fixed the change which takes place in the shape of numbers, and thus explained it, as far as it is explainable :—

$$\underset{\text{Oil of bitter almonds.}}{C_{14}H_6O_2} + \underset{\text{Oxygen.}}{O_2} = \underset{\text{Benzoic acid.}}{C_{14}H_6O_4}.$$

In like manner, the study of the change produced on the oil of potato spirit (amylalcohol) by the action of oxidising agents, discovered and expressed in numbers a definite relation between that oil and valerianic acid, previously quite unsuspected. It was proved, that these bodies are related to each other as alcohol to acetic acid.

$$\underset{\text{Alcohol.}}{C_4H_6O_2} + \underset{\text{Oxygen.}}{O_4} = \underset{\text{Acetic acid.}}{C_4H_4O_4} + \underset{\text{Water.}}{2\,HO}.$$

$$\underset{\text{Amylalcohol.}}{C_{10}H_{12}O_2} + \underset{\text{Oxygen.}}{O_4} = \underset{\text{Valerianic acid.}}{C_{10}H_{10}O_4} + \underset{\text{Water.}}{2\,HO}.$$

Human urine contains urea, often also uric acid ; in the urine of some classes of animals uric acid, in that of others urea, is absent. With the increase of uric acid, the proportion of urea diminishes ; the urine of the fætal calf contains allantoine; in human urine, oxalic acid is seldom absent. The change of certain vital operations with the body is accompanied by a corresponding change in the nature, amount, and quality of the compounds secreted by the kidneys. It is the duty of the chemist to express, quantitatively, the observed relations in which these compounds stand to each other, and to the process going on in the organism.

By analysis, chemistry first fixes the qualitative meaning of the words urea, uric acid, allantoine, oxalic acid, &c. By these formulæ no relation between them is produced; but when their characters and the changes which these compounds undergo under the influence of oxygen and water, the very substances which take a part in their formation or alteration in the organism, are examined, chemistry attains to the expression of a decided and unquestionable mutual relation. By the addition of a certain amount of oxygen to uric acid, it is resolved into three products, allantoine, urea, and oxalic acid. By a further addition of oxygen, uric acid is directly transformed into urea and carbonic acid. Allantoine presents a composition which may be regarded as that of the urate of urea. The comparison of the conditions discovered by the chemist to determine the transformation of uric acid into urea with those which accompany that change in the organism, leads to the conclusion, either that these conditions (in this case a supply of oxygen and of water) are the same in both cases, or that they differ. If they differ, the differences yield new starting points for research; and when these differences are ascertained and reduced to their causes, the process is explained, as far as chemistry can explain it.

Urea and uric acid are products of the transformation of the nitrogenised constituents of the blood, under the influence of oxygen and water. The relation between the nitrogenous bodies, uric acid, and urea on the one hand, and the oxygen of the air and the elements of water on the other, the quantitative conditions of the changes, are expressed by chemistry in formulæ, and, as far as chemistry reaches, they are explained.

It is evident, even to the uninitiated, that a difference in properties between two bodies depends either on a different arrangement of the elements of which they consist, or on a quantitative difference of composition. Chemical formulæ express both the different modes of arrangement, so far as these are known, and the quantitative variations which accompany those of quality. Modern chemistry, even with the aid of the most careful analysis, cannot fix the composition of an organic body with certainty, unless a quantitative relation be known between it and another body, the formulæ of which is ascertained beyond a doubt. It was only in this way that chemists were able to fix the formulæ of oil of bitter almonds, and of oil of potato spirit; and when simple observation does not disclose a relation between two bodies, the chemist is compelled, by experiments, to create, if possible, such relations. He endeavours to resolve one of the bodies into two or more products; he examines the products obtained by the action of oxygen, or of chlorine, of alkalies or of acids, and thus he at last succeeds in obtaining one or more products, the composition of which is known, and their formulæ discovered. He now connects the formulæ of the body under examination with those of the known products obtained from it. He makes out the sum of the whole from a knowledge of one, several, or all the parts of which that whole consists, or into which it may be resolved. Thus the absolute *number* of equivalents of carbon, hydrogen, and oxygen, in a molecule of sugar, cannot be fixed by the analysis of the sugar. The dexterity of a chemist gives us no proof of the accuracy of his analysis of salicine or amygdaline; but sugar combines with oxide of lead; it is resolved by fermentation into carbonic acid and alcohol, two compounds, the formulæ of which are accurately known.

Amygdaline is resolved into hydrocyanic acid, oil of bitter almonds, and sugar; salicine yields sugar and saligenine.

It is plain that when the weight of the body, and that of one, two, or all of the products derived from it, as well as their formulæ, are known, the number and proportion of one, of two, or of all its elements, in other words, its formulæ, may be deduced. The result of analysis may thus be confirmed or corrected.

The significance of chemical formulæ will now be obvious. The true formula of a substance expresses the quantitative relations, in which the body stands to one, two, or more others. The formula of sugar expresses the sum of all its elements, which combine with an equivalent of oxide of lead; and it also represents the sum of the weights of carbonic acid and alcohol, into which it is resolved by fermentation. We now see why the chemist is often compelled to split up into numerous products the substances whose composition he wishes to determine; and why, also, he studies its compounds with other bodies. These things all serve to control his analysis. No formula deserves entire confidence when the body, the composition of which it proposes to represent, has not been thus examined.

Let us illustrate this by the example of sugar. The analysis of sugar, often repeated, indicates that it contains, for every equivalent of carbon, one equivalent of hydrogen, and one of oxygen. But this analysis, however accurate, only tells us the relative properties of these elements, not their absolute amount in an equivalent of sugar. It cannot tell us what is the equivalent of sugar. We cannot say whether the true formula of sugar be C H O,

$C_2\ H_2\ O_2$, $C_4\ H_4\ O_4$, $C_6\ H_6\ O_6$, $C_9\ H_9\ O_9$, $C_{12}\ H_{12}\ O_{12}$, or any other multiple of C H O. To ascertain this, we first study its combinations, and we find that sugar combines with oxide of lead. The compound, being analysed, is found to contain, for one equivalent of oxide of lead, represented by the number 103·7, a weight of sugar represented by the number 180, a number much exceeding that of the weight of the oxide of lead. If we compare this number with those indicated by the supposed formulæ above given, among which we could not before fix on the right one, we found that these formulæ ($C = 6$, $H = 1$, $O = 8$), yield respectively the numbers 15, 30, 60, 90, 120, and 180. Assuming, therefore, the compound of sugar with oxide of lead to consist of one equivalent of each, it is manifest that the last formula, $C_{12}\ H_{12}\ O_{12} = 180$, is the right one.

We next proceed to study the products of the decomposition of sugar; and we find that, in fermentation, it yields no other products than alcohol and carbonic acid, the formulæ of which are known. That of alcohol is $C_4\ H_6\ O_2$; that of carbonic acid is $C\ O_2$. And, if we attend to the quantities of these products yielded by 180 parts of sugar, or one supposed equivalent, we find that 180 grains of sugar yield 92 grains of alcohol and 88 grains of carbonic acid. Now the equivalent of carbonic acid, $C\ O_2$, is $= 22$; 88 grains of the acid, therefore, correspond to 4 equivalents. In like manner, the equivalent of alcohol, $C_4\ H_6\ O_2$, is 46; so that 92 grains correspond to two equivalents of alcohol. We have found, therefore, that if the formula of sugar be supposed to be $C_{12}\ H_{12}\ O_{12}$, 1 equivalent of sugar yields 2 equivalents of alcohol, and 4 of carbonic acid; and if we add the formulæ in that proportion, the sum gives the formula of sugar.

Alcohol. Carbonic acid.

$$2\,(C_4\,H_6\cdot O_2) = C_8\,H_{12}\,O_4 \qquad 4\,C\,O_2 = C_4\,O_8$$

2 eq. alcohol. 2 eq. carbonic acid. 1 eq. sugar.

$$C_8\,H_{12}\,O_4 \quad + \quad C_4\,O_8 \quad = \quad C_{12}\,H_{12}\,O_{12}$$

Our formula, as deduced from the composition of the compound of sugar with oxide of lead, is therefore confirmed by the study of the products of its decomposition by fermentation.

There is still, however, another view possible. Sugar may have the formula $C_6\,H_6\,O_6$; and in that case, the compound with oxide of lead must contain 2 equivalents of sugar to 1 equivalent of oxide of lead, whereas we assumed it to contain 1 equivalent of sugar. In like manner, 1 equivalent of sugar, $C_6\,H_6\,O_6$, will yield, on fermentation, 1 equivalent of alcohol, and 2 equivalents of carbonic acid.

To decide this point, we have again recourse to the study of the products of decomposition of sugar. We find, that when exposed to a certain heat, especially in contact with bases, it loses a certain amount of water, and what may be called anhydrous sugar is left. Let us suppose, that sugar is so treated, and that 180 parts lose 27 of water, leaving 153 parts of anhydrous sugar combined with the base employed, from which it may be separated and again caused to take up the 27 parts of water it had lost, it is obvious, that in this case, the formula of the anhydrous sugar will be $C_{12}\,H_9\,O_9$; whereas, if we call sugar $C_6\,H_6\,O_6$, the anhydrous sugar will be $C\;6\;H\;4\tfrac{1}{2}\;O\;4\tfrac{1}{2}$, an impossible formula. We are, therefore, compelled to adopt the formula with 12 equivalents of carbon at least; there may be possibly, 24 or 48; but there cannot be less than 12. If we were to adopt the formula $C_4\,H_4\,O_4$, this would not agree with the results of fermentation, nor would $C_8\,H_8\,O_8$. And we have no reason to go higher than $C_{12}\,H_{12}\,O_{12}$, which suffices to explain all the facts observed. We conclude, from this last experiment, that sugar is thus constituted:— $C_{12} H_9 O_9 + 3 HO = C_{12} H_{12} O_{12}$; that is, one equivalent of anhydrous sugar, and 3 equivalents of water.*—(W. G.)

Some modern physiologists, forgetting that the knowledge of the mutual relations of two phenomena must precede their correct expression in numbers, have employed chemical formulæ in such a manner that their use degenerated into mere meaningless play with numbers, in their hands. Instead of searching for the expression of a relation or connection of dependence actually existing and manifested in the phenomena, they endeavoured to exhibit by numbers relations which did not exist in nature, and had never been observed. But this power does not in reality belong to numbers.

LETTER XXII.

It is not uncommon, in ordinary life, to meet with views and opinions concerning natural processes, of which strict science gives us no information. There are phenomena, the existence of which is asserted and defended by many, but is doubted and denied by others. Many of those opinions have obtained so

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* The above illustration is not given as an absolutely exact account of what takes place; for crystallised cane-sugar is $C_{12} H_{11} O_{11} = C_{12} H_9 O_9 + 2 HO$; and in fermentation it takes up 1 eq. of water, forming dry grape-sugar; $C_{12} H_{11} O_{11} + HO = C_{12} H_{12} O_{12}$. Crystallised grape-sugar is $C_{12} H_{14} O_{14}$; and in fermentation it loses 2 eq. of water; $C_{12} H_{14} O_{14} - 2 HO = C_{12} H_{12} O_{12}$. But, to avoid confusion, I have assumed cane-sugar to be $C_{12} H_{12} O_{12}$.—(W. G.)

much popularity, that even men of science are shy of expressing their well-founded doubts on the subject. Many of the opinions published by the admirers of Phrenology and Mesmerism belong to this class, and contribute not a little to render these dark parts of nature still more obscure and unfathomable.*

In the following pages I shall try to submit to examination what is called the spontaneous combustion of the human body; and this examination may perhaps serve as an example to illustrate the method pursued by science in similar cases, for testing the statements made, and ascertaining the truth.

More than a hundred and twenty years ago, in 1725, the remains of a woman, the wife of an inhabitant of Rheims, named Millet, were found burned in her kitchen, about eighteen inches from the open fireplace. Nothing was left of the body, except some parts of the head, of the legs, and of the vertebræ. Millet had a pretty servant girl, and the suspicion arose against him that he had murdered his wife. A criminal inquiry was instituted, but learned experts acknowledged spontaneous combustion, and Millet was pronounced innocent. This is the first, or one of the first, recorded cases of the so-called spontaneous combustion. It is easy to see that the idea of spontaneous combustion arose at a time when men entertained

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* (Note by the Editor.)—Although I cannot tell to what particular views the Author here refers, as being held by the admirers of Phrenology and Mesmerism; yet, as one long addicted to these sciences, I cannot let the above passage pass without expressing my earnest hope that my illustrious friend, Baron Liebig, may be induced to turn his attention to both subjects. He will then find, that although, as in all matters, especially when men of science hold aloof, error may have crept in, there are facts, in both, worthy of his most serious consideration, and such as will stand his most searching investigation. And I may remark, that it can hardly be said, either of Phrenology or of Mesmerism, that men of science have hesitated to express well-founded doubts; at least they have been ready enough to express such as were ill-founded.—W. G.

entirely false views on the subject of combustion, its essence, and its cause. What takes place in combustion, generally, has only been known for seventy years, that is, since the time of Lavoisier ; and the conditions which must be combined, in order that a body should continue to burn, have only been known within the last forty years, or since the time of Davy.

Since that first case, there have occurred, down to the present day, from forty-five to forty-eight cases, of which the great majority agree in the following points: —1. They took place in winter. 2. The victims were brandy drinkers, in a state of intoxication. 3. They happened where the rooms are heated by fires in open fire-places, and by pans of glowing charcoal, in England, France, and Italy. In Germany and Russia, where rooms are heated by means of closed stoves, cases of death, ascribed to spontaneous combustion, are exceedingly rare. 4. It is admitted that no one has ever been present during the combustion. 5. None of the physicians who collected the cases, and attempted to explain them, has ever observed the process, or ascertained what preceded the combustion. 6. It has also been invariably unascertained how much of combustible matter was on the spot. And, 7. It is also unknown how much time had elapsed from the commencement of the combustion to the moment when the consumed body was found.

The descriptions of cases of death from spontaneous combustion, which belong to the last century, are not certified by highly cultivated physicians ; they commonly proceed from ignorant persons, unpractised in observation, and bear in themselves the stamp of untrustworthiness. In these accounts, it is usually stated that the body entirely disappears, down to a greasy stain on the floor and some remains of bones. Every one knows that this is impossible. The smallest bit of bone, in the fire, becomes white, and loses somewhat of its bulk, but of its weight there remains from 60 to 64 per cent. of earthy matter, commonly retaining the form of the original bone.

In a very few cases it is not known whether fire from without, a spark, a lighted candle, or a red-hot coal, may not have caused the combustion.

The most learned and distinguished physicians, such as Dupuytren, Breschet, and professors of medical jurisprudence, such as Devergie, consider all the cases in which it is assumed that the body alone, without an external cause, such as a candle, a red-hot coal, or a spark, has begun to burn, and continued to burn, as incredible, unproved, and improbable. Dr. Franck (Encyclop. Wörterbuch, Berlin, 1843), out of forty-five cases adduced by him, excepts three, in which he admits this to have taken place.

A closer examination of the most important of these three cases will show what is to be thought of it. It is told by Battaglio, a surgeon in Ponte Bosio, (a surgeon in Italy in the year 1787 may be considered as equal to a bather or rubber.)

A priest, named Bertholi, goes to the market at Filetto, to transact business there, and lodges with his brother-in-law in that town. In his bed-room he has a sackcloth placed between his shirt and his shoulders, and when left alone, betakes himself to the reading of his prayer-book. A few minutes later, an unusual noise is heard in his room; he is heard to scream, and the people of the house find him stretched on the floor, surrounded by a light flame, which, as they approach, recedes, and at last disappears.

The skin (epidermis) of the right arm and of the surface from the shoulders down to the loins, was found detached from the flesh. The shoulders, protected by the sackcloth, were not injured; the sackcloth itself showed no trace of fire; on all the injured parts the shirt was consumed, and everywhere, where the dress was not burned, no injury was found below it. The drawers and legs were not affected by the burning.

Dr. Marc (Dict. des Sciences Méd. tom. vi. p. 85,) attaches singular importance to this case, and declares that it sheds light generally on the cause of the phenomenon of spontaneous combustion, which he thinks must be sought for in electricity.

This case is one chief support of the opinion, that a spontaneous combustion is possible, and there has been attached to it the idea of a very peculiar fire, which burns animal matter, without kindling the surrounding objects. But neither Marc nor Franck, who separate this case from the others, mention what is stated by more conscientious and accurate observers, namely, that, before the combustion, a lamp filled with oil was in the room, which lamp, after the event, was found empty, and its wick burned to ashes.

If we reflect, that the body was burned only where the shirt was consumed, that no marks of fire appeared on the other parts where this had not happened, and further, that the skin was not burned or charred, but only detached (it hung down in shreds) from the body, while the shirt was entirely burned and reduced to ashes, it is quite impossible to admit that the kindling and combustion of the shirt were caused by the skin, which yet did not itself burn; and no other explanation remains but that the shirt had caught fire, and that the burns or wounds were the results of its very superficial combustion. The presence of the lamp, which, as the disappearance of the oil proves, had burned, removes every doubt as to the origin of the fire.

With respect to the peculiarities which have sometimes been noticed in cases of so-called spontaneous combustion, namely, that substances, naturally combustible, do not take fire from contact with the burning human body, which again led to the conclusion of a peculiar kind of fire, different from ordinary fire, the report of Battaglia exhibits a striking example of this kind. He relates, that the priest's skull-cap was entirely consumed, without singeing the hair in the slightest degree ; and he adds, that he certifies this fact as thoroughly true and established. If we assume that the priest had the skull-cap on his head, which Battaglio obviously assumes (for had the cap been on a chair, and there burned, the fact of the hair not being singed would certainly have excited no wonder), then we must regard this as an accidental circumstance, from which no one will conclude that it was a peculiar kind of fire which consumed the cap. Whatever may have been the state of health or disease of the priest, it is certain that the skull-cap did not share in this state of health ; it was not diseased, and had in itself no cause to break out in flames ; nor if it did so, was there any reason why the flames should contain a fire different from all other kinds of fire, all of which burn hair.

This one example may serve to show how untrustworthy are the three solitary cases, in regard to which it is assumed that combustion occurred where no fire was in the neighbourhood.*

The admission of the spontaneous taking fire of the body, and of its consequent combustion, contradicts so greatly the known laws of combustion generally, and the known composition and quality of the body, that natural science has hitherto taken no notice of the statements made as to the fact, nor of their explanation.

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* The second example is one which a well-informed man can hardly venture to repeat; for, in the person to whom it occurred, the fingers of the right hand burned, and kindled the trousers, as also, by contact, the fingers of the left hand. This fire continued to burn when the burning parts were immersed in sand, and could not be extinguished by water. The third case occurred to a clergyman in America, who felt in the left leg a pricking pain, as if a hair had been torn out; he then saw at the spot a small light flame, which, when covered with the hand, was extinguished, and left a mark or burn, three quarters of an inch broad, and three inches long. Here, also, the clothes over the spot were burned through, but the skin was not burned; there was not even a blister;

With regard to the other forty-five or forty-eight cases of death, ascribed to spontaneous combustion, it is not supposed by the writers on the subject that the victims took fire of themselves, burst into flames, and were burned; but these writers admit that an external cause, a source of fire, was present. They assume that the body was set on fire by this fire, but that it then burned on, without external heat continuing to act on the body. They admit that the human body, in itself, is very difficult to burn, but that the flesh, skin, and other parts, in consequence of diseased conditions, caused by indulgence in ardent spirits and other causes, may become more combustible; not combustible like a bit of wood, which, when kindled and laid on the ground, soon goes out, but like a bundle of straw or a tallow-candle, which, once set fire to, continues to burn till nothing but ashes or charcoal is left.

The fact that some one, one hundred and twenty-five years ago, expressed the opinion that human bodies can burn in the way just described, and that, since that time, the same opinion has been held by some concerning forty-eight similar cases, affords not the slightest proof of the truth of that opinion.

There are historical proofs of an event: for example, that in this town, on a day and at an hour described, a person has been found dead, and burned. But there is no historical proof in favour of the opinion, that

the skin was as if scaled off, very dry, and of a dark colour. (Overton, American Journal, Nov., 1835). This kind of spontaneous combustion probably occurs very often to cigar-smokers; but, as told, it resembles a Yankee yarn, a joke of Uncle Sam, or of David Crockett. On the case of the sempstress Heinz, aged 17, in Hamburgh, Devergie remarks (Dict. de Méd. et de Chir., v., 375), "the process of healing of the burned parts destroys all the suppositions we might make concerning spontaneous combustion." Dr. Franck says of the same case (Encycl. Wörterbuch, vol. xxxi., p. 528), that he agrees with Kühn and Devergie, that Heinz, who was hysterical, had deceived the deceased Fricke, no one having seen the combustion.—J. L.

this person took fire spontaneously; and, in like manner, there are no historical proofs of the truth of the opinion that there exists a morbid state of the body, in consequence of which it acquires the combustibility of a bundle of straw.

To admit, as true, such opinions, the grounds on which they rest must, before all things, be recognised as true and free from doubt, and the facts with which these grounds are connected must be most exactly ascertained.

To demonstrate the truth of the first opinion, not only must we prove that it is possible for a piece of flesh to become thus combustible, but we must prove that such combustion, when it occurred, has proceeded from the flesh outwards.

With regard to the second opinion, it must be shown that a morbid state, such as is assumed, actually exists; and, further, that the persons who were burned were in that morbid condition.

Nothing of all this has been done. No one of those who are adherents of the theory of spontaneous combustion, or who, as authors, have endeavoured to support it, has ever occupied himself with experiments to learn the behaviour of animal matters in the fire. No one of them has ever in his life observed a morbid state, by which the body is rendered easily or quickly combustible. No one of them can tell the signs by which such a state may be recognised.

The supporters of that theory say, that the possibility of spontaneous taking fire, and the fact of spontaneous combustion in living or dead human beings, is not refuted by all that modern science knows. It is not their business to explain how this combustion is effected; they merely assert that it does take place. They say that circumstances and facts, quite unequivocal, in the recorded cases, speak in favour of this view. "How many phenomena," say they, "exist in nature, which science cannot yet explain! And yet these phenomena do not, on that account, cease to be true. How many unknown forces may yet exist, of which modern Chemistry has not even a presentiment! And is it just or fair, or even decent, to reject, off-hand, the testimony of so many men who have avowed their belief in spontaneous combustion, and to class them with liars or blockheads, simply because we do not agree with them?"

All these remarks are no such grounds as are required to justify an opinion; for every kind of assertion may be defended by similar statements, if it contradict common sense. They apply to all. These reasoners entirely forget, that nobody doubts the facts of the deaths by burning in these cases, any more than the existence of a number of unexplained phenomena is doubted. The fact stands sure; but the explanation does not. What they assert, is not the fact; this fact or occurrence is, and continues to be, true, even without their assertion of it. But not so, that the death occurred in the way imagined by them, and can only be explained in that way. It is a fallacy to say that they do not try to explain the fact; for they do actually try to explain it by asserting that the body has become combustible and has been burnt, of itself, without external aid, and in virtue of a cause residing in itself. But to comprehend or admit this explanation, we must obviously ask for the proofs which support it; and when it appears that there are no such proofs, or that those adduced are fallacious, that is, that they contradict known and established truths, we cannot admit, as true, their explanation of the fact of burning, namely, how and in what way a man takes fire spontaneously.

When a physician declares that a man has died by suffocation, or from an inflammation of the lungs, this presupposes that he is acquainted with the accident or the disease which preceded the death; or he must, after death, have recognised the signs of asphyxia, or on dissection have found those of inflammation. If he know nothing of all this, it is impossible, even for the ablest man, to form an opinion as to the cause of death.

The opinion that a man can burn of himself is not founded on a knowledge of the circumstances of the death, but on the reverse of knowledge—on complete ignorance of all the causes or conditions which preceded the accident and caused it.

Let us suppose a man to have died suddenly, and a number of circumstances to point to the conclusion that he has been poisoned. A legal investigation, dissection, and chemical search, is ordered; but no sign of poisoning, no trace of poison, is found. If now, on the ground that more than a hundred years before, a poison existed, the Aqua Tofana, with which many men were poisoned—a poison which causes death and eludes all research, leaving no traces of its action; if, I say, the experts were to offer this explanation, that the absence of all signs indicating the cause of death showed that death had been caused by this Italian poison, what would a reasonable man say to such an opinion, in such a case? And what would he say, if to the question, What, then, is the Aqua Tofana? he received the answer that no one knew, that there were many things which we did not know, without being compelled to doubt the existence of the Aqua Tofana?

Those who assume death to be caused by spontaneous combustion place themselves exactly in the position of the experts. There is found, in a room, a woman or a man, dead, and burned. The experts are ordered to make a report on the case, but cannot discover in what way the fire occurred, or how it was propagated in the body; nor can they give any account of the degree of the burning or destruction of the body; and since for more than a century cases very similar have occurred, in which it was supposed to be true that the combustion originated spontaneously, or that the body was set fire to by an external cause, and then continued to burn, they classify the present case with the others, and explain it in the same way as the others have been explained.

Because they could not discover that the death had been caused by external causes, and the destruction of the body had been effected by burning fuel applied to it;—from utter ignorance, therefore, of all which preceded the death, they deduce a positive cause, for the very existence of which all proof is wanting; which is not only in the highest degree doubtful, but which also contradicts the best known laws of the burning and of the combustibility of animal bodies.

To explain an occurrence which is not understood, they fly for aid to a cause which itself is not understood. Instead, therefore, of saying that the case before them, for want of sufficient knowledge, is unexplainable, they maintain that this want is a proof that spontaneous combustion has taken place; a phenomenon which also, from want of sufficient knowledge, they are unable to explain, but which must be true, because similar cases have been so explained for more than a hundred years.

The insufficiency and error of such a conclusion hardly requires to be more distinctly pointed out.

The authors who have expressed and defended the opinion, that spontaneous combustion exists and must be admitted, are not persons who by their position and their occupation were so placed as to become intimately acquainted with the action of fire on animal bodies, such as cooks, male and female; but have usually been persons who had no opportunities of practically acquiring this knowledge.

The proofs which they adduce are taken, contrary to all the rules of logic, from the case itself. The death and destruction of the body, the cause of which is to be discovered, are adduced as proofs that the imagined cause is the true one.

By the existence, thus assumed, of spontaneous combustion, the cases are explained; and these same cases, which really require to be explained, are adduced as proofs of the existence of spontaneous combustion.

As another main argument for spontaneous combustion, is adduced the fact, that in the majority of cases the body has been destroyed or consumed in such a degree, that we cannot suppose enough of fuel to have been present, external to the body, to produce the actual effect. Consequently, and precisely for this reason, an internal cause, in the body itself, must have contributed to the result; that is, the body must have supported the combustion by its own mass.

With respect to the fuel, assumed to have been present in insufficient quantity, this is a very insecure supposition; for fire, the cause of death by burning, has this peculiarity, that it consumes the fuel or matter which supports it, so that the fuel does not remain unaltered, like the knife with which a man has been murdered.

We cannot therefore possibly judge, after the burning, how much fuel has been present before it; for that which remains is only a part of the whole of the fuel which has acted; and it is precisely that part which has disappeared, or has been consumed, that produces the effect.

With regard to the writers who defend the theory of spontaneous combustion, or the conscientiousness and trustworthiness of their statements, we must, above all things, consider their capacity for forming a judgment. To have this capacity, a necessary previous condition is, that they have the required knowledge. They must know what combustion in general is; and what takes place in it;—they must have observed the cases, and must really have had the sincere intention of investigating the process, and of ascertaining everything that can assist in explaining the occurrences, without any preconceived opinion.

When we apply this measure in judging of the trustworthiness of the writers on spontaneous combustion, of all that they assert and believe, nothing remains but the narration of a death or of a number of deaths, by burning. I have already mentioned, that not one of them was present during such a combustion; and they take the cases, which they relate, either from unauthenticated newspaper notices, or they relate them after other narrators, who, like themselves, have seen none of the cases. All of them, without exception, assume the existence of spontaneous combustion as true; and they are occupied, not in investigation and testing, but in showing how the occurrence, which of course they did not see, took place.

These circumstances clearly show in what stage of cultivation these men stand, and how little qualified they are to give a valid judgment on these occurrences. As a general rule, the cases narrated by others, unattested as to the mode of occurrence, are used by them to support a theory imagined by themselves. That which, in the stories, favours the theory, is brought out, and all that opposes or refutes it, is either passed over in silence, or designated as secondary in importance. These men are not students of a natural phenomenon, striving to ascertain the existence and the truth of spontaneous combustion; they are advocates for the opinion or theory, that spontaneous combustion exists.

We cannot wonder that, fifty or a hundred years ago, there were distinguished physicians, who believed and defended the spontaneous combustion of the human body, at a time when the essence and nature of combustion, generally, was hardly known; but the modern authors who defend this opinion, are, for the most part, men, whose qualifications for judging, or whose powers of observation, and whose possession of the necessary knowledge, are not proved by other genuine scientific labours or investigations in their department of science, and whose names are only known because they have appeared as defenders of the opinion in question.

The distinct and unhesitating way in which, in many works on medical jurisprudence, the known cases are related and the different theories of spontaneous combustion are explained, has had the bad effect of inducing many well-informed practical physicians, contrary to their better conviction, to allow spontaneous combustion to pass for established truth, and not to contradict the statements and opinions of the supporters of that theory, in order to avoid being regarded as heretics in medicine.

Every one now knows that, when, in these days, a man is accused of having poisoned another, above all and before all, the poison must be detected, and it must be proved that the accused has used this poison to accomplish his criminal intention. In times, in which the means of detecting poisons with the greatest certainty were not yet known, the rack was used to make the discovery. It is hardly necessary to remind you, that this instrument was employed with so much success, that thousands of human beings confessed that they could exercise sorcery and witchcraft. The stake no longer stands ready for sorcerers and witches, not because it has been proved that there are no witches or sorcerers, but because the enlightened study of nature has succeeded in demonstrating that all the things of which these unfortunate victims of ignorance and superstition were accused, must be ascribed, not to the devil, but to natural causes. These thousands were judicially murdered on the scaffold, or at the stake, by the advocates of the opinion, that sorcery and witchcraft, *as the results of a compact with the evil one,* are possible and really exist. But when, at a later period, the reasons for this opinion were inquired into, and all the facts on which it rested, accurately and conscientiously examined and tested, it appeared that everything which appeared to support the popular opinion rested on false or fallacious observations—on fallacious explanations—on error—or on deliberate falsehood.

Precisely so is it with the other reasons, collected from experience or from science, with which the defenders of the theory of spontaneous combustion strive to support it, and to prove or render intelligible the supposed process. The reasons derived from experience are in part true, but do not apply to the cases. Those taken from science, the so-called theoretical reasons, are, without exception, fallacious, and also fail to explain the cases.

Thus, for example, a butcher in Neuburg, ninety-nine years ago, had an ox which was sick and much swollen. When opened, there flowed out of the belly an inflammable air, which was kindled, and then burned with a flame five feet high. The same thing was observed by Morton in a dead pig, by Ruysch and Bailly in dead human bodies, which had been swollen in an extraordinary manner by the disengagement of gases.

Resting on these facts, the adherents of the theory of spontaneous combustion assume that disease may produce a state of body in which a combustible gas is disengaged, which accumulates in the cellular tissue, and, when kindled by an external cause, by a flame, or by the electric spark, effects the combustion of the body. We may easily perceive that the conclusion has no connection with the facts on which it is grounded.

1. The accumulation of gas in the cellular tissue has only been observed in dead bodies, and indeed in such as were far gone in putrefaction and enormously swollen. Besides, the gas did not, in these cases

escape through the skin, till a cut was made through skin and cellular tissue. Lastly, the gas indeed burned, when kindled, but the body was not thereby kindled; it had not become spontaneously combustible, or indeed combustible at all, and was not burned.

2. In such as are supposed to have died from spontaneous combustion, a swollen state, such as is caused by accumulation of gas, has never been observed; but they were perfectly healthy.

The explanation in question is, therefore, obviously entirely untenable.

Another writer assumes that in certain diseased states a gas, phosphuretted hydrogen, is produced, which takes fire on contact with air; and that the spontaneous and easy combustibility of the body must be ascribed to this very easily and spontaneously combustible substance.

There exists, indeed, such a gas, phosphuretted hydrogen, which takes fire instantly on mere contact with air; but this gas loses that property by a short contact with gypsum, charcoal, paper, oil of turpentine, &c.; and with regard to its presence in the human body, it has never been observed, either in health or in disease, nay, not even in the putrefaction of dead bodies; and what is more important, the human body contains no phosphorus in such a state as to yield by any process, during life or after death, phosphuretted hydrogen gas.

The fact of the existence of phosphuretted hydrogen is undoubted; but its formation and its presence in the human body are certainly false; no observation whatever speaks in favour of its formation there. This gas, again, is in the highest degree poisonous, as much so as arsenic; and its presence in the blood of a living animal is quite irreconcileable with this property.

Others again ascribe the assumed easy combustibility of the human body to the presence of an unusual proportion of fat, or to the circumstance that from the abuse of ardent spirits, it is, as it were, steeped in spirits, and therefore burns like a candle or a spirit lamp, when kindled from without.

This notion depends on an erroneous conception of combustibility, or on ignorance of the conditions of combustion.

We cannot render a substance which burns with difficulty easily combustible by means of one of easy combustibility, but only by removing the cause which renders it difficult of combustion; or by increasing its surface, and consequently the access of air, which is indispensable to the process.

When we steep a sponge or clippings of paper in brandy or spirits of wine, and kindle the latter, the sponge and the paper are not found more combustible than they were by themselves. The brandy burns away, and then the paper perhaps takes fire, but never till all the brandy has been burned off, and then not better than if it had not been steeped in brandy. The sponge, under these circumstances, does not burn.

In like manner, when a piece of flesh is thrown into boiling fat, and the fat is kindled, the fat burns, but not the flesh. It is not kindled, and does not continue to burn, even when the fat is all burned. Flesh is not rendered easily combustible by the presence of fat.

Every one knows that a wisp of straw burns easily. The cause of this is its loose texture, in consequence of which every straw is surrounded by air. But when the straw is chopped into small pieces, it burns with difficulty; nay, it may be used to extinguish a fierce fire, by throwing on the fire so much chopped straw as covers the fuel completely. The burning body ceases to burn, because by the chopped straw the access of air is prevented.

When brandy is poured over a plum pudding and kindled, the brandy burns, but when it is all consumed, the pudding does not take fire.

Cotton, which when loose is easily combustible, becomes in the form of a wick difficultly combustible in an oil lamp. It is burned and charred only where the air has access to the wick.

We can render paper clippings or sponge easily combustible by steeping them in solution of saltpetre, and drying them; that is, by a substance which is not itself combustible. But we cannot do this by means of an easily combustible substance.

The presence of brandy or an excess of fat cannot then give to the human body an easy combustibility which does not belong to it naturally. To burn the body in that state fire must be applied from without, and must continue to act in it, after the brandy and the fat are consumed.

Dry animal substance such as flesh is not in itself difficult of combustion; indeed up to the charring point it is easily combustible, as may be seen in a piece of horn, or in shavings of horn. Even bones may be kindled by a small fire, and will then continue to burn if placed in heaps, without further application of external fire, till they become as white as chalk, being reduced to ashes. Flesh dried, that is deprived of the greater part of its water, behaves exactly as horn does. Tissues and membranes also when dry are easily destroyed in the fire. All these substances become difficult of combustion in consequence of the water they contain in the fresh state, which in the flesh and other soft parts amounts to 75, and in the blood to 80 per cent. The water is contained in these tissues as in a sponge, the pores of which are very fine. It cannot, as is well known, be heated in the open air, even by the fiercest fire, beyond its boiling point. But this temperature, 212° F., is very far from high enough to kindle the animal matter; even fat requires, to kindle it, a temperature of about

800° F., about four times higher than that of boiling water.*

All substances, the kindling heat of which lies higher than 212° F., become difficultly or rather not at all combustible when in a porous form, and steeped in water; for so long as water is present the combustible body cannot burn, even in the fiercest fire. Only when the water has been boiled off, does the temperature of the substance rise higher, and at the kindling point it bursts into flame.†

It is, therefore, easy to see how even the presence of fat does not render the body easily combustible; for so long as it retains any water, the fat does not take fire, because, for that, a higher temperature is required. The fat melts and runs out, and when the heated animal parts have lost their water by evaporation they would be kindled and burst into flame, even if no fat were present. The presence of fat, since it also burns, makes the flame larger, but does not render the flesh more combustible. The body can only be rendered rapidly combustible by the addition of highly oxidised substances; thus, by means of nitric acid, cotton, linen, and sawdust become so exceedingly easily kindled and so very combustible, that they may be used instead of gunpowder.

No special theory is required to enable us to see

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* No one considers white of egg combustible; because every one knows that the water which renders it fluid is not combustible, and that burning bodies are extinguished when covered with water. Coagulated albumen is not more combustible; for it retains almost the whole water. Now the water in soft animal tissues is in the same state as in coagulated albumen; and these parts, from containing so much water, cease to be combustible.

† When wet paper is held over a spirit flame, the paper will not burn till all the water is dissipated. The dry parts burn; those which are still wet do not. The paper does not burn on, because the heat is not sufficient to dry the part nearest that which is burning, and to raise it to the kindling point. But the essential condition of continued burning is that the burning part shall give to the next the necessary temperature.

that the fat of an animal body exposed to the fire, when it flows into the fire and burns there, contributes to the further destruction of the body. The flame of burning fat of course acts on flesh just as does the flame of burning spirits; and every one knows that with the latter we can produce the same effects as with wood or coals.

In the living body one circumstance opposes its being set fire to and burned, which is absent in the dead body; namely, the circulation of the blood. In a piece of flesh acted on by fire, the fluids which moisten it remain where they are till evaporated; but in a living body there flows through all, even the minutest parts, a current of blood which causes this result, that the heated portions are constantly carried away and replaced by cooler portions. If the fire without be very fierce, a reaction takes place from the blood, consisting in a flow of water outwards towards the heated point. The skin is detached from the subjacent parts, and a blister, full of water, is thus formed. So long as the current of blood continues, the body may be injured by external heat; but it cannot burn, or become burned or charred, till the circulation has ceased; that is, till death has taken place.*

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* Many of the adherents of the theory of spontaneous combustion admit that in the healthy state a living body cannot take fire of itself and burn; they assume that there exists a morbid state, in which, as products of diseased action, compounds are formed of much greater inflammability than is usually possessed by animal matters. This is a mere fancy, without even the shadow of observation to support it. All nitrogenous bodies require for combustion a higher temperature than carbon or hydrogen. It is a peculiarity of these bodies, that by containing nitrogen they lose in a great measure their inflammability. On this account, nitrogenised compounds are not reckoned among combustibles. Ammonia, a compound of nitrogen and hydrogen, is no longer combustible; it cannot be kindled by a red-hot body, and does not burn. Even phosphorus, in the phosphuret of nitrogen, loses its inflammability. We cannot imagine a nitrogenised body which, by transformation,

Spontaneous combustion in a living body is therefore absolutely impossible. Even phosphorus, a body so eminently combustible, loses, under similar circumstances, its combustibility; as when it is prepared for matches, and its particles, in a fine state of division, are surrounded by particles of water.

That excess of fat, or the presence of brandy in the body, is not the cause of easy combustibility and does not render the body easily kindled, is most strikingly demonstrated by the fact, that hundreds of fat, well fed brandy-drinkers do not burn, when by accident or design they come too near a fire. It may with certainty be predicted, that, so long as the circulation continues, their bodies would not take fire, even if they held a hand in the fire till it was charred.

The most remarkable theory is one which supposes that spontaneous combustion is caused by electricity, or by the electric spark. Muncke, formerly Professor of Physics in Heidelberg, says on this point in Gehler's physikalisches Wörterbuch, vol. x. p. 262:—"In these matters electricity must, before all things, be excluded from the explanations; for nothing determines its increased development, and, as no isolation exists, this is rather to be regarded as impossible; and we have no such electrical spark as is required to kindle combustible matter." The theory in question is founded on a statement made by the traveller Brydone, that he knew a lady whose hair became so electrical

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should yield compounds more inflammable than hydrogen, which requires a red heat to kindle it in the air. A man, weighing 120 lbs., has about 90 lbs. of water in his body. If we suppose this water in a boiler, and the solid parts, bones, flesh, &c., to be burned dry under it, then, even admitting that they should take fire when heated and continue to burn, like wood, the heat given out by their carbon and by the hydrogen which is not expelled in the form of ammonia, is not enough to convert into vapour all the water in the kettle.

by combing it, that whenever it was combed sparks were seen. Another fact is, that a senator, named Drayton, in the United States, observed electrical sparks when drawing off his stockings, whether of wool or of silk. These facts are most probably true, (such facts are of every-day occurrence.—W. G.); but the use made of them by the defenders of the theory of spontaneous combustion appears to be at least absurd; for the property of hair or of silk to become electrical by friction, belongs, not to the body, but to every wig and to every stocking. The electricity does not proceed from the interior of the body, for the hair when cut off, or the stocking when removed, equally possess it. The body is, on the contrary, the greatest obstacle to the observation of the electricity of these substances; and it is only in rare cases that the skin is so dry, or of such a quality, that the hair or silk become electric by friction, in spots of their contact with the skin. This property of developing electricity has never been observed in the body of persons supposed to have perished by spontaneous combustion, either before or after death, and when sparks have occurred, the hair or silk has never once been set fire to.

I cannot better characterise the opinions alluded to, and the persons who regard spontaneous combustion as an historical truth, and defend it, than by quoting the theory of one of the most ancient writers, F. J. A. Strubel, in his work, "The Spontaneous Combustion of the Human Body, with especial reference to its medico-legal significance. A treatise, written under Prof. Dr. J. Wilbrand, Ordinary Public Teacher of Medical Jurisprudence in the University of Giessen, and laid before the medical faculty there. Giessen, 1848."

This theory is as follows:—On the ground of Brydone's observation, he proceeds—"If, in the human body, the development of electricity, from whatever cause, is so increased, or the electricity so accumulated or condensed, that it is discharged outwards in sparks, spontaneous combustion may occur, and that for the following reasons: the electric sparks, traversing the body in all directions, must not only decompose, to a greater or less extent, the water which constitutes four-fifths of the body, but must also kindle the products of its decomposition, its elements, oxygen and hydrogen, whether this be caused by mechanical compression or by chemical action, a point on which men of science differ. But oxygen, when mixed with hydrogen, and kindled, as in the cases before us, produces the most intense heat, in which the diamond is easily dissipated. According to this explanation, that which formerly appeared most marvellous, namely, its extraordinary rapidity, the shortness of the time in which it takes place, is at once understood; and we can only feel surprised if the contrary occur. It would also explain how the fat of the body may be set on fire, and continue to burn."

This theory is a pattern of its kind. Its author has not the remotest conception of the laws of the production and accumulation of electricity, of the conditions of the formation of the spark, of the decomposition of water by electricity. It is sufficient here to observe, that when electricity decomposes water, no spark ensues; and when a spark ignites the gases, water is formed, and not decomposed into its elements. But, assuming everything to happen as he imagines, that water is decomposed, and that the elements, by the decomposing agent, are again converted into water, the body, by the kindling of the gaseous mixture, would, in less than a second, burst into thousands of fragments, like a mortar filled with gunpowder; and yet it would not burn, in spite of the high temperature, because the whole of the oxygen is at once seized by the hydrogen, and no free oxygen remains for the combustion of the body. Oxygen and hydrogen, when produced by the electrical decomposition of water, form the so-called explosive gas, distinguished by the property of exploding with a violent report when kindled. A hollow ball, of small size, made of paper or of swine's bladder, and filled with this gaseous mixture, explodes, when kindled by an electric spark, with a report as loud as that of a cannon ; but the paper and the bladder do not take fire nor burn.

With respect to the extraordinary rapidity of the supposed spontaneous combustion, this is a mere invention ; for in the cases in which persons have been found dead, nothing whatever is known of the course of the accident.

The same remark applies to the character of the flame, which is said not be extinguished by water. All the evidence for this (rapidity of combustion and inextinguishable flame) is derived from one case which was described, not by a physician, not even by a surgeon of those days, nor by a bather, but by a priest named Boineau. It was that of a woman of eighty, who drank nothing else than brandy. She began to burn, sitting on a chair, and burned, although water was poured upon her, till all the flesh was consumed. The skeleton alone remained, sitting in the chair. This case is related in a letter dated the 22nd of February, 1749, and is therefore one hundred and one years old. The narrator was not present, and did not see the flame ; and the story plainly indicates a good intention on his part,—that of inoculating his flock with a wholesome terror for brandy-drinking. This explains the resemblance between the flame of the burning tippler and hell-fire. The chair, which had not sinned, of course did not burn, and was only slightly singed on the surface.

The notion of the rapidity of the combustion, and the peculiar character of the flame, assumed in the remaining forty or fifty cases, rest on this case alone ;

for, in all the others, the people were found burned to death, who had been seen alive five, six, or twelve hours before. Nothing more is known of these cases.

The most striking proof of ignorance of the laws of combustion, and of incapacity to form a judgment on the cases of supposed spontaneous combustion, in the defenders of that notion, is this, that they lay the greatest stress on circumstances quite insignificant, which have no relation to the question; while they regard as non-existent the most important facts. This is the case, for example, with the vapours, smoke, and smell which fill the room in which burned persons are found, and the viscid, brown, greasy deposit which is observed on the furniture, window-panes, mirrors, &c. All this is regarded as a peculiarity and distinctive sign of spontaneous combustion. Now this deposit, as every one knows, consists of solid combustible particles, and of liquid products, formed by the action of heat on animal and vegetable matters, such as flesh, blood, paper, &c.; but, of course, only when these particles have not burned; for these solid and liquid portions are very combustible, and their non-combustion depends on a want of oxygen, and of the temperature necessary for their taking fire. The solid parts of smoke are called, in general, soot; the liquid parts are called tar. The deposit on the furniture and windows is a thin coating of animal soot and tar. Like these, it feels greasy, and is exactly like the coating which is at first formed in the chambers where meat is smoked, and which covers the meat itself. With a little of what is called in German "Glanzruss," or lustrous soot, which is a kind of lamp-black not freed from oil or tar, when mixed with water, we can give to glass and wood the same coating; only here we see the strokes of the brush, which, of course, are absent when the deposit settles uniformly on objects from the air. Moreover, among the products of the action of heat on animal matter, is a compound of sulphur (sulphuret of ammonium), which renders white-lead paint brown or black.

These products, soot, tar, &c., are formed when heat acts on combustible animal or vegetable matters, *which do not burn*, (as in the dry or destructive distillation, and in the making of vegetable or animal tar), and are an irresistible proof that the parts which yield them have not undergone combustion; for had they done so, and had air enough been present, they would have been consumed; that is, entirely oxidised; and nothing would have remained, capable of forming a deposit on glass or furniture.

It is in the nature of the thing, that a person who has now and then smelled rose-water, and remembers its odour, shall be able, in many cases, to distinguish rose-water from eau de Cologne; but to assert that by the smell, which fills a room, we can tell whether it arise from spontaneous combustion or not, or that we can discover whether the deposit on the furniture arises from a body which has spontaneously taken fire, and not from leather (the covering of cases, &c.), paper, wood, hair, clothes, &c., all of which have been also exposed to heat; and this, too, when the observer has never had an opportunity of becoming acquainted with the peculiarities of the smell or the deposit from a body which has really undergone spontaneous combustion, if such peculiarities there be, and consequently without a recollection of these things,—goes far beyond any thing that we can ask a man of sense to believe. It is nothing short of an insult to the healthy human understanding.

The conclusions to which the theory of spontaneous combustion leads, are in such decided contradiction with all experience, that the explanation offered by the adherents of that theory has not met with the smallest acceptation on the part of one distinguished physician, in any degree acquainted with the natural sciences. As long as medicine has existed, no case has ever occurred in which a married couple, at the same instant, have been seized with inflammation of the lungs, or any other disease, and in which, in both man and wife, the disease has run the same course, and both have died at the same moment. How many improbable suppositions in regard to the state preceding invasion of the disease, must be made, before such a result can be supposed possible! Now the adherents of spontaneous combustion find this quite in the natural order of things, in regard to the disease or morbid state which precedes the combustion; for they relate a case in which a tailor, named Larivière, with his wife, both being intoxicated, after having been left at seven in the evening, were found, at eleven next day, converted into a shapeless charred mass, with the exception of some fragments. The man who can ascribe such an occurrence to disease, or to a morbid cause, must find it an easy task to swallow a camel. That several persons, in a room where the vapours of burning charcoal accumulate, are suffocated at the same time, is a case, unfortunately, which only too often occurs.

The adherents of spontaneous combustion regard it as a peculiarity of that process, that when it happens, no cry for help is heard (obviously because the victims are dead before they are burned). This is just as if we were to regard it as a peculiarity of burglary that the people of the house do not hear the noise made by the thieves in entering it. Such a robbery only succeeds when the people of the house do not hear the noise; that is, when they are absent or asleep; and of course a man can only be burned to coal and ashes when no one hears his cries for help. If people were near, and if he were able to cry for help, he would not be allowed to be burned to death.

It has been concluded, from the fact of no cry being heard, that the death is not only rapid, but painless; and in this case we can only wonder that such a pleasant death is not desired for all good Christians, since all must die of some disease, and spontaneous combustion, on this theory, is a disease, although an unusual one.

In order to explain why a particular part is burned, it is of course always assumed that the seat of the disease was in that part. If the abdomen and intestines are burned, the disease was in the belly; if the head and neck are burned, the disease was in them; and it was in the arms and legs where they suffered. Wherever the effect appears, the cause is placed, and the presence of the cause is explained or proved by the effect. This is contrary to all the rules of logic.

The theory is so elastic, that it can be made wide or narrow, just as we require it. If the burn is severe, the disease was severe; if the burn is superficial, so was the disease. Two square inches of skin on the leg are diseased, and set fire to the trousers; but all round this spot the skin is quite healthy, as in other men. If unconsciousness be required, it is there; but if, with the head on fire, consciousness is wanted for certain actions, it also is there. When it has been ascertained, as far as such a thing can be ascertained, that the person burned was never intoxicated, and had a horror for brandy, then it is insinuated that he probably drank in secret. We see how error—and this theory is an error—only produces delusion, contradictions, and new errors. There is only one path to the truth, crossed by a thousand crooked paths, at each of which credulity stands to point the way. Truth has it rights, which cannot be infringed with impunity: it has its signs, by which every unprejudiced man recognises it.

The defenders of this theory explain why a part of the clothes on the burning body is not burned, by one cause or another; it is a peculiarity of this phenomenon which is observed. And when the burning body, which did not set fire to the clothes, sets fire to a bureau or a sofa, this is explained by other causes. The clothes are burned above, on the breast, and there the flames acted like other flames; but below the epigastrium the clothes did not burn; this is the result of the peculiar quality of the flame!

It is impossible for any one who was not present to explain the most trifling and insignificant specialities in such cases; and to demand such an account of these is foolish; for to explain them presupposes a knowledge of the whole occurrence, and that is unknown. Many of these specialities depend on causes which are never again combined, and which are on that very account called accidental.*

From what has been said, I trust that the reader will be enabled to appreciate the true value of the opinion, as well as of the cases of spontaneous combustion; and to see why science has paid no regard to such a theory, destitute of every shadow of foundation.

The close relation between brandy-drinking and death by burning is so obvious, that it is hardly necessary further to allude to it. In the case of a person intoxicated, deprived of all reflection, and incapable of all judgment concerning danger, and what is connected with it, we may suppose any proceeding, even the most unlikely. We may imagine that in this state a man on going to bed, and extinguishing his candle, sets fire to the bed and curtains; that he goes to bed in winter near a closed stove, and with a

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* If any one, for example, throws a sixpence into the air, it may happen that it falls into a chink of the floor, and presents to us its edge, and stands upright. But if the same person, in the same room, throws up the same coin a hundred thousand times, it may occur that it never once falls into the chink, and, even if this were to happen a million of times, it might never fall into the same spot of the chink. We cannot, with the best intentions, bring together the conditions necessary for this result; the coin falls on another spot. This kind of events is ascribed to chance.

pan of burning charcoal; or in looking for a bootjack under the bed, he may leave the light which he used standing under the bed. Innumerable suppositions, equally probable, sufficiently account for the breaking out of fire in a room, in which there is a human being and also a light; and if the person be still completely intoxicated, the danger is increased in the same proportion as his accountability is diminished. He is like a child that has no idea of the action of fire. Three years ago, an unfortunate child crept on a limekiln to sleep, and had the limbs burned from the feet upwards, in a dreadful manner. Such is the true relation between brandy-drinking and burning. All that is said of flames from the throat of drunkards is entirely false. No one has ever seen these flames; the man who tells the story has always had it from another narrator; it is only certain, that compassionate street vagabonds, when they find a man dead drunk, often employ the liquid that drips from dunghills to extinguish the internal fire, against which it is said to be a sovereign remedy.*

Exact experiments, made with this object, have proved that air, saturated with the vapour of alcohol at blood heat, cannot be kindled, and does not burn with flame.

When fire occurs in a room or in a house, the proprietor and the insurance companies have the greatest interest in ascertaining how it arose, and who caused it. In most cases, this is not ascertained, because he who purposely sets fire to a house does not confess to

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* There are few words used in so many senses as the word "to burn." We burn ourselves in a flame; the injured part burns (subjectively) for many hours afterwards. Brandy burns with flame, but it also burns in the mouth, and when we drink it, it burns in the body. A brandy-drinker dies; his last complaint was of the fire in his inside; hence, obviously, has arisen the notion of his being burned alive by the brandy in his body.

doing so; neither does he who does it from carelessness. But when the cause remains unknown, no one believes that it has broken out spontaneously, and without the aid of some person.* And if a cat be found burned to death in the room, no one will imagine that the fire has arisen from the spontaneous combustion of the cat, or suppose, because a cat's fur sometimes becomes electric by rubbing with the hand, that a disease exists among cats, by which they become spontaneously combustible. Yet this supposition is not more improbable than in the case of men. It may be said that cats drink no brandy; but the defenders of the theory of spontaneous combustion admit, that spontaneous combustion, precisely in those cases where they suppose no light to have been present, and the body to have taken fire spontaneously, occurs in persons not addicted to ardent spirits.

In cases of fire, when the investigation is extended to all those who had access to the place where it broke out, it often happens that the incendiary, or the accidental originator of the fire, is discovered. Legal medicine, even if the theory of spontaneous combustion were true, which it is not, ought not to interfere in so simple a proceeding, justified as it is by experience, until all other probable causes of fire have been excluded; and if this be, notwithstanding, done, those who so act deprive legal medicine of its proper rights, and become partakers of the incendiary's guilt; they protect the criminal by misleading the investigation. The physician, who is called on for a judgment in such cases, can only say, if he act according to duty and conscience, in what state the body was found,—whether the injury from burning took place before or after death,—whether death was

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* Except in cases where masses of charcoal powder, or tow and cotton steeped in oil, as often happens in certain manufactories, are set fire to by the oxidising agency of the atmosphere.—W. G.

caused by fire alone, or before the action of the fire by other causes,—such as wounds, strangulation, a blow on the head, &c. In no case is it permitted to him to explain anything he has not seen, by cases which he has also not seen, or by a theory which he cannot understand.

LETTER XXIII.

The discoveries of chemistry in the domain of physiology have in recent times given us unexpected information in regard to many of the most important processes in the animal organism, and have led us to clearer views concerning those things to which the names of poisons, food, or remedial agents must be applied. The notions of hunger and of death are no longer confined to a mere description of symptoms.

It is now ascertained with positive certainty, that all the substances which constitute the food of man must be divided into two great classes, one of which serves for the true nutrition and reproduction of the solid parts of the animal body, whilst the other ministers both to the performance of these processes, and also to quite different purposes.

We can prove with mathematical certainty, that as much flour or meal as can lie on the point of a table-knife is more nutritious than five measures (about eight or ten quarts?) of the best Bavarian beer; that a person who is able daily to consume that amount of beer, obtains from it, in a whole year, in the most favourable case, exactly the amount of nutritive constituents which is contained in a five pounds loaf of bread, or in three pounds of flesh.

The entire subversion of all our former notions concerning the share taken by beer, sugar, starch, &c., in the vital process, gives to a more intimate knowledge of the recent researches, and the consequently prevalent views on this subject, a certain degree of interest.

The primary conditions of the maintenance of animal life are, a constant supply of food, that is, the stilling of hunger; and of oxygen, in the shape of atmospheric air, that is, the process of respiration. During every moment of life, oxygen is absorbed from the atmosphere in the organs of respiration; and the act of breathing cannot cease while life continues.

The observations of physiologists have demonstrated that the body of an adult man sufficiently supplied with food, neither increases nor diminishes in weight during twenty-four hours, and yet the quantity of oxygen absorbed into his system, in that period, is very considerable. According to the experiments of Lavoisier and of Menzies, an adult man takes into his system from the atmosphere, in one year, no less than seven hundred to eight hundred pounds weight of oxygen; and yet we find his weight at the end of the year either exactly the same, or differing one way or other by at most a few pounds. What, it may be asked, has become of the enormous amount of oxygen thus introduced into the human system in the course of one year? We can answer this question satisfactorily. No part of the oxygen remains in the body, but it is given out again, combined with carbon and hydrogen. The carbon and hydrogen of certain parts of the animal body have combined with the oxygen introduced through the lungs and skin, and have passed off in the forms of carbonic acid and vapour of water. At every expiration and every moment of life, a certain amount of its elements are separated from the animal organism, having entered into combination with the oxygen of the atmosphere, in the body itself.

In order to obtain a basis for an approximate calculation, we may assume, that in an adult man, the weight of the whole mass of the blood is twenty-four pounds, of which 80 per cent. is water. Now, from the known composition of the blood, we know that in order to convert its whole amount of carbon and hydrogen into carbonic acid and water, there is required a quantity of oxygen, which is taken into the system of an adult man in four or five days. Whether the oxygen enters into combination directly with the elements of the blood, or with the carbon and hydrogen of other parts of the body, it follows inevitably—the weight of the body remaining unchanged and in a normal condition—that as much of these elements as will suffice to supply with them twenty-four pounds of blood, must be taken into the system in four or five days; and this necessary amount is furnished by the food.

We have not, however, remained satisfied with mere approximation: we have determined accurately, in certain cases, the quantity of carbon taken daily in the food, and of that which passes out of the body in the fæces and urine combined—that is, uncombined with oxygen; and from these investigations it appears that an adult man, taking moderate exercise, consumes $13\frac{9}{10}$ ounces of carbon, which pass off through the skin and lungs as carbonic acid gas.*

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* The numbers just given are the average of the consumption of 856 soldiers in barracks, whose food—bread, potatoes, flesh, pease, lentils, beans, even butter, salt, and pepper—was, for a month, most accurately weighed, and each article subjected to elementary analysis. Three guardsmen, who had, besides the daily allowance of 2 lbs. of bread, an addition of 2½ lbs. for each period of payment, and a drummer, who had a like allowance, were exceptions to the average. In this calculation is not included the carbon of the fresh vegetables, or sour crout, nor that of the portion of food taken by the men in the evening at the public-house.

It requires 37 ounces of oxygen to convert $13\frac{9}{10}$ of carbon into carbonic acid. Again; according to the analysis of Boussingault, (Annales de Chim. et de Phys., lxx. i. p. 136,) a horse consumes $79\frac{1}{10}$ ounces of carbon in twenty-four hours; a milch cow 70¾ ounces; a pig, fed with potatoes, 21½ ounces. So that the horse requires 13 pounds 3½ ounces; the cow 11 pounds 10¾ ounces; and the pig about 3½ pounds, of oxygen.*

As no part of the oxygen taken into the system of an animal is given off in any other form than combined with carbon or hydrogen, and as in a normal condition, or state of health, the carbon and hydrogen so given off are replaced by those elements in the food, it is evident that the amount of nourishment required by an animal for its support must be in a direct ratio with the quantity of oxygen taken into its system. Two animals which in equal times take up by means of the lungs and skin unequal quantities of oxygen, consume an amount of the same food unequal in the same ratio. The consumption of oxygen in a given time may be expressed by the number of respirations; it is, therefore, obvious that in the same animal the quantity of nourishment required must vary with the force and number of respirations. A child breathes quicker than an adult, and, consequently, requires food more frequently and pro-

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According to the estimation of a serjeant, each man daily consumes, on an average, 3 oz. of sausages, ¾ oz. of butter, ½ pint of beer, and $\frac{1}{10}$th of a pint of brandy; the carbon of which is more than double that of the fæces and the urine together. The fæces, on an average, amount daily to 5¾ oz.; they contain 75 per cent. of water, and the dry residue contains 45·24 per cent. of carbon, and 13·15 per cent. of ash. 100 parts of fresh fæces contain, therefore, 11·31 of carbon, very nearly the same as an equal weight of flesh. In the above calculation, the carbon of the fæces and urine has been assumed as equal to that of the green vegetables and of those articles which are consumed in the evening at the public-house.

* 17½ ounces = ½ kilogramme.

portionably in larger quantity, and bears hunger less easily. A bird deprived of food dies on the third day, while a serpent, confined under a bell, respires so slowly that the quantity of carbonic acid generated in an hour can scarcely be observed, and it will live three months, or longer, without food. The number of respirations is fewer in a state of rest than during labour or exercise: the quantity of food necessary in both cases must be in the same ratio. An excess of food, and a want of a due amount of respired oxygen, or of exercise, as also great exercise (which obliges us to take an increased supply of food), and weak organs of digestion, are incompatible with one another.

But the quantity of oxygen received by an animal through the lungs not only depends upon the number of respirations, but also upon the size and expansion of the lungs, and the rapidity of the circulation. The number of pulsations in a given time gives a tolerably accurate measure of the velocity of the current of blood through the lungs, although it cannot tell us the exact quantity of the blood flowing to them, which depends on the interior size of the cavities of the heart. All these things exert a decided influence on the consumption of oxygen, and consequently on the amount of food required. Two persons, or two animals, with a different number of pulsations or a different volume of lungs, consume, in like circumstances, a different amount of food; he who has the smaller lungs consuming less. If both consume the same amount of food, it may happen that one remains thin, while the other becomes fat. The right appreciation of the size of the chest gives to the experienced agriculturist a secure means of judging of the milking qualities of two cows, or of the fattening qualities of two oxen or pigs, otherwise similar.

In summer the air is not only warmer and less dense, and consequently contains less oxygen than colder air, but it contains aqueous vapour; in winter it is nearly dry. The space occupied by the vapour in the warm air is, in winter, filled by air; that is to say, an equal volume of air in frosty weather contains more oxygen than in summer.

In like manner, the absolute quantity of oxygen in the inspired volume of air varies with the height of the barometer. At the level of the sea a cubic foot of air contains more oxygen than the same volume of air does on high mountains. In the inhabited elevated plateaus of central America, at the height of 8000 to 10,000 feet, the air contains in an equal volume nearly one-third less oxygen than in the deep shafts of the Cornish tin mines. But these variations in the density of the air from temperature, evaporation, or pressure, exert no perceptible influence on the quantity of oxygen taken up by the blood in every second of time, and therefore have no notable effect on the daily amount of food required.

The consumption of oxygen is entirely dependent on the respiratory motions and on the circulation of the blood; and this explains the influence of the exhausting heat of tropical climates, and the greater consumption of oxygen in cold air; the former diminishing, and the latter increasing, the number and depth of the respirations.

The mutual chemical action of the constituents of the food and of the oxygen conveyed by the circulation to all parts of the body is the *source of animal heat.*

LETTER XXIV.

THE source of animal heat, its laws, and the influence it exerts upon the functions of the animal body, constitute a curious and highly interesting subject, to which I would now direct your attention.

All living creatures, whose existence depends upon the absorption of oxygen, possess within themselves a source of heat, independent of surrounding objects.

This general truth applies to all animals, and extends to the seed of plants in the act of germination, to flower-buds when developing, and fruits during their maturation.

In the animal body, heat is produced only in those parts to which arterial blood, and with it the oxygen absorbed in respiration, is conveyed. Hair, wool, and feathers, receive no arterial blood, and therefore in them no heat is developed. The combination of a combustible substance with oxygen is, under all circumstances, the only source of animal heat. In whatever way carbon may combine with oxygen, the act of combination is accompanied by the disengagement of heat. It is indifferent whether this combination takes place rapidly or slowly, at a high or at a low temperature: the amount of heat liberated is a constant quantity.

The carbon of the food, being converted into carbonic acid within the body, must give out exactly as much heat as if it had been directly burned in oxygen gas or in common air; the only difference is, the production of the heat is diffused over unequal times. In oxygen gas the combustion of carbon is rapid and the heat intense; in atmospheric air it burns slower and for a longer time, the temperature being lower.

It is obvious that the amount of heat liberated must increase or diminish with the quantity of oxygen introduced in equal times by respiration. Those animals, therefore, which respire frequently, and consequently consume much oxygen, possess a higher temperature than others, which, with a body of equal size to be heated, take into the system less oxygen. The temperature of a child (102°) is higher than that of an adult (99·5°). That of birds (104° to 105·4°) is higher than that of quadrupeds (98·5° to 100·4°) or than that of fishes or amphibia, whose proper temperature is from 2·7° to 3·6° higher than that of the medium in which they live. All animals, strictly speaking, are warm-blooded; but in those only which possess lungs is the temperature of the body quite independent of the surrounding medium.

The most trustworthy observations prove that in all climates, in the temperate zones as well as at the equator or the poles, the temperature of the body in man, and in what are commonly called warm-blooded animals, is invariably the same; yet how different are the circumstances under which they live!

The animal body is a heated mass, which bears the same relation to surrounding objects as any other heated mass. It receives heat when the surrounding objects are hotter, it loses heat when they are colder, than itself.

We know that the rapidity of cooling increases with the difference between the temperature of the heated body and that of the surrounding medium; that is, the colder the surrounding medium the shorter the time required for the cooling of the heated body.

How unequal, then, must be the loss of heat in a man at Palermo, where the external temperature is nearly equal to that of the body, and in the polar regions, where the external temperature is from 70° to 90° lower!

Yet, notwithstanding this extremely unequal loss of heat, experience has shown that the blood of the inhabitant of the arctic circle has a temperature as high as that of the native of the south, who lives in so different a medium.

This fact, when its true significance is perceived, proves that the heat given off to the surrounding medium is restored within the body with great rapidity. This compensation must consequently take place more rapidly in winter than in summer, at the pole than at the equator.

Now, in different climates the quantity of oxygen introduced into the system by respiration, as has been already shown, varies according to the temperature of the external air; the quantity of inspired oxygen increases with the loss of heat by external cooling, and the quantity of carbon or hydrogen necessary to combine with this oxygen must be increased in the same ratio.

It is evident that the supply of the heat lost by cooling is effected by the mutual action of the elements of the food and the inspired oxygen, which combine together. To make use of a familiar, but not on that account a less just illustration, the animal body acts, in this respect, as a furnace, which we supply with fuel. It signifies nothing what intermediate forms food may assume, what changes it may undergo in the body; the last change is uniformly the conversion of its carbon into carbonic acid, and of its hydrogen into water. The unassimilated nitrogen of the food, along with the unburned or unoxidised carbon, is expelled in the urine or in the solid excrements. In order to keep up in the furnace a constant temperature, we must vary the supply of fuel according to the external temperature; that is, according to the supply of oxygen.

In the animal body the food is the fuel; with a proper supply of oxygen we obtain the heat given out during the oxidation or combustion of that fuel. In winter, when we take exercise in a cold atmosphere, and when consequently the amount of inspired oxygen increases, the necessity for food containing carbon and hydrogen increases in the same ratio; and by gratifying the appetite thus excited, we obtain the most efficient protection against the most piercing cold. The oxygen taken into the system is given out again in the same form, both in summer and winter: we expire more carbon at a low than at a high temperature, and require more or less carbon in our food in the same proportion; and, consequently, more is respired in Sweden than in Sicily, and in our own country an eighth more in winter than in summer. Even if an equal weight of food is consumed in hot and cold climates, Infinite Wisdom has ordained that very unequal proportions of carbon shall be taken in it. The fruits used by the inhabitants of southern climes do not contain, in a fresh state, more than 12 per cent. of carbon, while the blubber and train oil which feed the inhabitants of polar regions contain 66 to 80 per cent. of that element.

From the same cause it is comparatively easy to be temperate in warm climates, or to bear hunger for a long time under the equator; but cold and hunger united very soon produce exhaustion.

A starving man is soon frozen to death. The animals of prey in the arctic regions, as every one knows, far exceed in voracity those of the torrid zone.

In cold and temperate climates, the air, which incessantly strives to consume the body, urges man to laborious efforts, in order to furnish the means of resistance to its action, while, in hot climates, the necessity of labour to provide food is far less urgent.

Our clothing is merely an equivalent for a certain amount of food. The more warmly we are clothed the less urgent becomes the appetite for food, because the loss of heat by cooling, and consequently the amount of heat to be supplied by the food, is diminished.

If we were to go naked, like certain savage tribes, or if in hunting or fishing we were exposed to the same degree of cold as the Samoyedes, we should be able with ease to consume half of a calf, and perhaps a dozen of tallow candles into the bargain, daily, as warmly clad travellers have related with astonishment of these people. We should then also be able to take the same quantity of brandy or train oil without bad effects, because the carbon and hydrogen of these substances would only suffice to keep up the equilibrium between the external temperature and that of our bodies.

According to the preceding expositions, the quantity of food is regulated by the number of respirations, by the temperature of the air, and by the amount of heat given off to the surrounding medium.

No isolated fact, apparently opposed to this statement, can affect the truth of this natural law.

The cooling of the body, by whatever cause it may be produced, increases the amount of food necessary. The mere exposure to the open air, in a carriage, or on the deck of a ship, by increasing radiation and vaporisation, increases the loss of heat, and compels us to eat more than usual. The same is true of those who are accustomed to drink large quantities of cold water, which is given off at the temperature of the body, 98·5°. It increases the appetite, and persons of weak constitution find it necessary, by continued exercise, to supply to the system the oxygen required to restore the heat abstracted by the cold water. Loud and long continued speaking, the crying of infants, moist air, all exert a decided and appreciable influence on the amount of food which is taken.

The unequal loss of heat in summer and winter, in cold and hot climates, is not the only cause which renders necessary unequal quantities of food. There are other causes, which exert a very decided influence on the amount of food required.

To these causes belong bodily exercise, and all kinds of bodily labours and exertion. The consumption of mechanical force in the body is always equal to a waste of matter in the body, and this must be restored in the food. When a man or an animal works, a certain amount of food must be added ; increased work and effort without a corrresponding increase of food, cannot be continued for any length of time ; the health of the man or animal soon gives way.

But the waste of matter or the force exerted always stands in a certain relation to the consumption of oxygen in respiration ; and the quantity of oxygen taken up in a given time determines, in all seasons, and in all climates, the amount of food necessary to restore the equilibrium.

While the labourer, in winter, with equal consumption of force and of oxygen, is compelled to obviate the loss of heat by warm clothing (bad conductors of heat), in summer he is bathed in perspiration. If the amount of food and that of oxygen, be equal in summer and in winter, the development of heat is also equal.

The whole process of respiration appears most clearly developed, when we consider the state of a man, or other animal, totally deprived of food. The respirations are unchanged ; oxygen, as before, is taken up from the air, and carbonic acid and water are given off. We know with certainty, whence the carbon and hydrogen are derived, for as the starvation continues, we see the carbon and hydrogen of the body diminishing.

The first effect of starvation is the disappearance of fat, and this fat cannot be traced either in the urine or in the scanty fæces. Its carbon and hydrogen have been given off through the skin and lungs, in the form of oxidised products; it is obvious that they have served to support respiration.

In the case of a starving man, $32\frac{1}{2}$ oz. of oxygen enter the system daily, and are given out again in combination with a part of his body. Currie mentions the case of an individual who was unable to swallow, and whose body lost 100 lbs. in weight during a month; and, according to Martell (Trans. Linn. Soc., vol. xi. p. 411), a fat pig, overwhelmed in a slip of earth, lived 160 days without food, and was found to have diminished in weight, in that time, more than 120 lbs. The whole history of hybernating animals, and the well-established facts of the periodical accumulation, in various animals, of fat, which, at other periods, entirely disappears, prove that the oxygen, in the respiratory process, makes a selection among the substances which are capable of entering into combination with it. It combines first and chiefly with those substances which have the greatest attraction for it.

In the progress of starvation, however, it is not only the fat which disappears, but also, by degrees, all such of the solids as are capable of being dissolved. In the wasted bodies of those who have suffered starvation, the muscles are shrunk and unnaturally soft, and have lost their contractility; all those parts of the body which were capable of entering into the state of motion have served to protect the remainder of the frame from the destructive influence of the atmosphere. Towards the end, the particles of the brain begin to undergo the process of oxidation, and delirium, mania, and death close the scene; that is to say, all resistance to the oxidising power of the atmospheric oxygen ceases, and the chemical process of eremacausis, or decay, commences, in which every part of the body, the bones excepted, enters into combination with oxygen.

The time which is required to cause death by starvation depends on the amount of fat in the body, on the degree of exercise, as in labour or exertion of any kind, on the temperature of the air, and finally, on the presence or absence of water. Through the skin and lungs there escapes a certain quantity of water, and as the presence of water is essential to the continuance of the vital motions, its dissipation hastens death. Cases have occurred, in which a full supply of water being accessible to the sufferer, death has not occurred till after the lapse of twenty days. In one case, life was sustained in this way for the period of sixty days.

In most chronic diseases death is produced by the same cause, namely, the chemical action of the atmosphere. When those substances are wanting, whose function in the organism is to support the process of respiration; when the diseased organs are incapable of performing their proper function of producing these substances; when they have lost the power of transforming the food into that shape in which it may, by entering into combination with the oxygen of the air, protect the system from its influence; then, the substance of the organs themselves, the fat of the body, the substance of the muscles, the nerves, and the brain, are unavoidably consumed.

The true external cause of death in these cases is the respiratory process, that is, the action of the atmosphere.

A deficiency of food, and a want of power to convert the food into a part of the organism, are both, equally, a want of resistance: and this is the negative cause of the cessation of the vital process. The flame is extinguished, because the oil is consumed; and it is the oxygen of the air which has consumed it.

In many diseases substances are produced which are incapable of assimilation. By the mere deprivation of food, these substances are removed from the body without leaving a trace behind; their elements have entered into combination with the oyxgen of the air.

From the first moment that the function of the lungs or of the skin is interrupted or disturbed, compounds, rich in carbon, appear in the urine, which acquires a brown colour.

Many, perhaps most, chronic diseases in man, are caused by a misproportion, or a disturbed relation of equilibrium on the operations of the digestive and excretory organs, considered with reference to the lungs. Retaining the familiar illustration of the furnace, every one knows, that the accumulation of soot in the chimney, or the throwing on of an excess of fuel, interrupts the functions of the fire-place; that these causes act as would a stoppage of the grate below, through which the air has access.

In the machine of the body, so infinitely perfect, there is a thoroughly equal relation of mutual dependence between the lungs, the intestinal canal, and the kidneys.

Experienced and well-informed physicians have long known, that the kidneys and intestines are the regulators of the respiratory process. The lower intestine is an organ of secretion; it is the chimney of the organism. The fetid constituents of the excreta are the soot, separated from the blood by this intestine; while the urine contains those constituents of the smoke, so to speak, which are soluble in water, or in alkaline or acid liquids. The notion that the solid excreta consist of putrescent matters, and that their fetor depends on this, is quite erroneous. Experiments on this point have proved that the solid excreta of the cow, horse, and sheep, and of healthy men, are not putrescent. No putrescent substance has a smell similar to that of these excreta; and all these fetid products may be artificially produced, in all their nauseous peculiarities, by processes of partial oxidation applied to albumen, fibrine, &c. The urine of the horse and cow, moreover, contains a substance in considerable quantity, which, when acted on by acids, yields a pitchy matter, quite similar in its aspect to *tar*, and, as the most remarkable product, carbolic acid, or hydrated oxide of phenyle, the chief ingredient of common wood tar and of creosote. This shows, that the illustration of the furnace is a true one; since we actually obtain, as the products of imperfect oxidation, or combustion in the body, substances which are formed by the imperfect oxidation or combustion of organic matter in furnaces.

By the simultaneous and harmonious co-operation of the chief organs of secretion, the blood is kept in the state of composition and of purity fit for the nutritive process. Excess in eating, so much indulged in in every country, is an overloading of the grate with fuel. In the bodies of perfectly healthy persons, a slight excess of matters which pass from the stomach into the blood, produces, nevertheless, no disturbance of the vital functions; because that part of them which in a given time is not consumed in respiration, is sent out of the body more or less altered, through the intestines or the kidneys. These organs mutually aid each other in the process. When, as the result of an overloading of the blood with combustible matter, and a consequent deficiency of oxygen, the urine, from excess of unoxidised organic matters (in the form of uric acid, &c.,) is dark coloured and turbid, this is generally a sign of deficient activity of the intestine; and in this case, a simple purgative, by the action of which, the unoxidised matters are removed from the blood, generally restores the disturbed equilibrium, the disturbed proportion of these matters to the inspired oxygen; the urine becomes transparent as usual, and recovers its natural colour. (Prout.)

The lung is in itself passive; the process which takes place in it is not, as in the glands and secretory organs determined by an internal, but by an external cause. In the lung is wanting the powerful activity which in other organs, opposes external disturbances and removes their effects. The mere inspiration of dust (of organic or inorganic solid particles,) causes organic deposits in the pulmonary tissue, which are also produced in a similar way by internal causes. Smoke and soot accumulate in the lungs or other tissues in the form of abnormal deposits in all cases where the proper action of the intestine and the kidneys is impeded or arrested by causes of disease.

Between the lungs and the liver we find a similar relation of mutual dependence. In the lower orders of animals, and in the fœtus, the size of the liver is in an inverse ratio to the undeveloped or imperfectly developed organs of respiration; and even in the higher classes of animals, a small lung usually corresponds to a large liver, in healthy individuals. (Tiedemann.) The liver, roughly sketched, is the magazine for the matters destined for respiration; it is the workshop, in which they receive the shape and quality fitted for the production of animal heat. The liver is small, with a large well-developed lung; the quicker and more perfectly the fuel is consumed, the less of it accumulates in the magazine for fuel, the size of which has the most definite relation to the rapidity of the consumption.

Respiration is the falling weight—the bent spring, which keeps the clock in motion; the inspirations and expirations are the strokes of the pendulum which regulate it. In our ordinary time-pieces, we know with mathematical accuracy the effect produced on their rate of going, by changes in the length of the pendulum, or in the external temperature. Few, however, have a clear conception of the influence of air and temperature on the health of the human body; and yet the research into the conditions necessary to keep it in the normal state is not more difficult than in the case of a clock.

LETTER XXV.

THE changes which the air undergoes in respiration have been examined with great care in recent times, and a knowledge of the results obtained is of importance to the preservation of health.

The lungs, as the scene of the respiratory process, consist of an arborescent ramification of tubes which become continually smaller, the last twigs of which end in minute sacs or bladders, called air-cells, and communicate by the bronchi and trachea with the cavities of the mouth and nose. The walls of the air-cells are penetrated by a close net-work of very minute blood-vessels, so that the air in the cells is only separated from the blood by a membrane excessively thin, and with the blood in these vessels the air comes into immediate contact through the fluid which, proceeding from the blood, moistens the walls of the blood vessels. The small vessels gradually unite to form larger twigs and branches, which pour their contents into the heart through a few large trunks. The heart is divided by a partition into a right and a left half, each of which has again an auricle and a ventricle, communicating by an opening provided with valves. The contraction of the heart is the primary cause of the motion of the blood. By the contraction of the right ventricle, the blood from the right auricle and the veins which flow into it, is forced through the so-called pulmonary arteries into the lungs, and returns from the lungs through the so-called pulmonary veins to the left auricle and ventricle, from which last, by its contraction, it is forced through the great arterial trunk, or aorta, into the ramifications of the arterial system throughout the body. By the veins it returns as venous blood to the right auricle, and from that it passes to the right ventricle, to recommence the circulation, which lasts as long as life continues. The contraction of the heart produces the beating of that organ and the pulsation of the arteries. With every stroke of the heart there is sent from it through the pulmonary arteries in the adult, calculating from the capacity of the right ventricle, a quantity of blood, estimated by physiologists at five or six ounces (Volkmann); and consequently there flows through the lungs in one minute, taking the pulsations at seventy-two, the astonishingly large quantity of from 22 to 27 lbs. of blood.

While the blood flows through the pulmonary vessels with so great a velocity, the air in the air-cells is continually changed by the respiratory motions. In health, and in a state of rest, there are fifteen or sixteen respirations per minute; in a state of moderate exertion, twenty in the same time. With more violent motion, the strength and fulness, as well as the rapidity of the respirations increase. The quantity of expired air differs according to the size of the individual and that of the pulmonary cavity; but we may assume that an adult man, on an average, expires ½ litre, or about 30 to 31 cubic inches of air; while, with strong and deep respiration, this quantity may be increased to about 60 cubic inches.

The human lungs retain, in ordinary respiration, six to eight times as much air in the cells as is changed in each respiration. The fresh air inspired mixes with the air in the cells; at each expiration a part of this is expelled, and its volume replaced by an equal bulk of fresh air.

In the minute net-work of vessels in the lungs, an immense surface of venous blood, therefore, comes in contact through the walls of the air-cells with the inspired air. The blood, in these circumstances, instantly undergoes a very marked alteration; the dark, nearly black red colour of venous blood, changes into the bright red of arterial blood; and the continuance of the vital functions and of life is most intimately connected with the new properties which the blood acquires, along with the change of colour produced by contact with the air.

Simultaneously with the change of colour in the blood, the air undergoes an essential change in its composition; and to this we shall now turn our attention.

The chief constituents of atmospherical air are oxygen, nitrogen, a small quantity of carbonic acid, and of ammonia, and, besides these, mere traces of combustible gases. The air always contains moisture or aqueous vapour in very variable proportion.

The means employed by chemists to determine the quantity of the constituents of air are extremely simple. Hydrated potash, or caustic potash, absorbs more than 100 times its volume of carbonic acid, and it is easy to see that the increase of weight in a tube, filled with potash, through which we conduct slowly a cubic foot of dry air, informs us exactly how much carbonic acid this cubic foot of air contained. Just as carbonic acid is absorbed by potash, oxygen is absorbed by red hot copper; and if we cause a cubic foot of dry air, purified from carbonic acid, to pass through a red hot tube filled with copper turnings, all the oxygen remains with the copper, and the gain of weight of the tube gives exactly the amount of oxygen in this cubic foot of air, the total weight of which is also known (Dumas).

In this way it has been ascertained that dry air, free from carbonic acid, contains in 1000 parts 231 parts of oxygen and 769 parts of nitrogen by weight. Since oxygen is heavier than nitrogen, the proportions by volume are somewhat different. In 100 volumes of dry air as above, there are 21 volumes of oxygen and 79 of nitrogen (or 20·9 exactly of oxygen: Dumas, Brunner, Bunsen, Regnault); and in ordinary atmospheric air there is found, on an average, 1 volume of carbonic acid in 2000 volumes of air, or, by weight, 0·75 of carbonic acid in 1000 parts by weight of air.

The expired air differs very much in composition from the atmospheric air.

If we introduce into a glass tube, closed at the upper end, graduated in equal divisions, and filled with dry expired air, the lower open end being immersed in mercury, about 1-40th of the volume of the air of strong solution of potash, the volume of the air instantly diminishes, the carbonic acid present being absorbed by the potash. If now we add to the potash a concentrated solution of pyrogallic acid, about half the volume of the potash, the mixture absorbs the oxygen as rapidly as red hot copper does. The volume again diminishes, to a degree exactly corresponding with the amount of oxygen present; and the residue is nitrogen.

In this way it is found that 100 volumes of expired air, in ordinary normal respiration, contain from 3·5 to 5 volumes of carbonic acid, and 16·5 to 15 volumes of oxygen. The air first expired contains less carbonic acid; but when respiration is very deep, it contains even more, in many cases 8·5 to 9 volumes of carbonic acid, and only 11·5 to 11 volumes of oxygen in 100.

The amount of oxygen in pure air is therefore diminished, by its contact with the blood in the lungs, to the extent of $\frac{1}{5}$th or $\frac{1}{4}$th, while the carbonic acid is increased above 100 times. It is obvious that the change of venous into arterial blood, and its change of colour, depend on a separation of carbonic acid gas, which mixes with the air, and an absorption of oxygen, which combines with certain constituents of the blood. A certain amount of oxygen passes from the air into the blood; and the air receives, in the place of this oxygen, a quantity of carbonic acid, the volume of which is usually somewhat smaller.

According to Prout, the amount of carbonic acid in the expired air is greater, in a state of mental tranquillity and of moderate exercise, and when the barometer is low. In general, the per centage of carbonic acid diminishes when the respirations are quick, but in this case the whole amount of carbonic acid expired in a given time is much greater. According to experiments made on this point, it appears, that with 6 respirations per minute the expired air contains 5·7 per cent, with 12 respirations 4·1, with 24 respirations 3·3, and with 48 respirations 2·9 per cent. of carbonic acid. The entire quantity of expired carbonic acid was, for 6 respirations per minute, 11 cubic inches; for 12, 25·3 cubic inches; and for 48, 44·5 cubic inches of carbonie acid. (Vierordt.)

The influence of stronger and quicker respirations on the respiratory process is thus evident. By this means there is effected, in a given time, a more effectual separation of carbonic acid, or decarbonisation of the blood.

It can hardly be doubted, that with the increase or diminution of carbonic acid expired, the amount of oxygen entering the blood stands in a definite relation; and that, consequently, the blood, in the same time in which it gives off more carbonic acid, receives more oxygen from the air.

Blood, when agitated with air, takes up more than $\frac{1}{10}$th of its own volume of oxygen, and this gas may be very nearly entirely expelled by agitation with carbonic acid gas. When blood, saturated with carbonic acid, is agitated with air, carbonic acid is displaced, and in its stead oxygen is taken up, which, in like manner, may be again expelled by carbonic acid.*

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* There are two opposite views concerning the form in which the absorbed oxygen is contained in the blood. One of these con-

The blood of a horse, not agitated with air, but, as it flowed from the vein, yielded to Magnus, when saturated with carbonic acid, more than $\frac{1}{10}$th of its volume of oxygen gas. In this process, the blood

siders the separability of the oxygen gas by an excess of carbonic acid gas, as a convincing proof that this oxygen is not chemically united with the blood, but is only mechanically absorbed in it. But this expression for the phenomenon is decidedly erroneous. For while 1,000 volumes of water, agitated with air, and fully saturated therewith, absorb only 9¼ volumes of oxygen and 18½ volumes of nitrogen (Gay Lussac); 1,000 volumes of blood, according to the admirable experiments of Magnus, take up 100 to 130 volumes of oxygen, and only 17 to 33 volumes of nitrogen. It is obvious, therefore, that the oxygen gas absorbed by the blood can only be in part mechanically absorbed in the liquid; for the liquid in blood is water, of which we know that in the same circumstances it absorbs 11 to 14 times less oxygen. On the contrary, we must admit, that the greater absorptive power of the blood is determined by the presence of certain constituents, which have a more powerful attraction for oxygen than water has. The degree of attraction, with which the oxygen is retained in the compound which it forms in the blood, is very small; but this is no reason for believing, that it is not chemically combined. We are able to augment the absorptive power of water for many gases, by adding to it substances, which have a chemical attraction, however weak, for the gas. When, for example, we add to the water phosphate of soda, its power of absorbing carbonic acid gas increases; and 1 per cent. of the salt causes the water to take up twice as much of the gas as pure water would have done under the ordinary pressure. A solution of green vitriol (sulphate of iron) in water takes up forty times more of the deutoxide of nitrogen or nitric acid gas than pure water. The absorbed gases are separated from both liquids in vacuo, and may also be expelled, in the former case by mere agitation with air, in the latter by agitation with carbonic acid gas. No one thinks of regarding this fact, so analogous to what is observed in the blood, as a proof that the carbonic acid in the solution of phosphate of soda, or the nitric oxide in that of green vitriol, is only mechanically absorbed and not in the form of a chemical compound, because we know, that the absorptive power of the water in these cases depends on the quantity of the dissolved salt. But if the amount of gas absorbed increases in a definite ratio with the amount of salt in the solution, it is quite certain that the absorption of the gas depends on the salt, and not on the water.

There are two causes on which the absorption of a gas, or the absorptive power of a liquid depends. One is, a pressure on the takes alternately the bright red colour of arterial or the dark purple red of venous blood.

These facts prove that carbonic acid and oxygen gases, in their action on the blood, are opposed to

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gas which is in contact with the liquid, and this cause is external. The other is a chemical attraction acting from the particles or constituents of the liquid on the gas.

In all the cases, in which a gas is not chemically but only mechanically retained in a liquid, the quantity of gas absorbed depends solely on the external pressure, and increases or diminishes as the pressure is increased or diminished. In the cases adduced, when the solution of phosphate of soda is saturated with carbonic acid gas by agitation with it, (and has taken up twice as much of this gas as water would do under the ordinary pressure,) the absorptive power of the solution, when the pressure is doubled, does not increase in the same, but in a far smaller ratio. The saturated solution of phosphate of soda now behaves to carbonic acid under double the pressure as would water, saturated with the gas at the ordinary pressure. The increase of absorptive power is not greater than in water, because the chemical attraction which at first increased the absorptive power does not continue to act ; but when it has produced its proper effect (the formation of a chemical compound), ceases to act further. In the same way, the solution of green vitriol, saturated with nitric oxide, under the ordinary pressure, behaves towards that gas under increased pressure as would water, saturated with it at the ordinary pressure. If 100 volumes of that solution are saturated, under the usual pressure by 100 volumes of the gas, the liquid, under a double pressure, absorbs, not 100 volumes more of the gas, but only 10 volumes, not more than water, previously saturated at the ordinary pressure, takes up under the same circumstances.

The blood agrees perfectly with these liquids in its mode of action on gases. Were the oxygen in the blood only mechanically absorbed, the blood, which takes up out of air, containing as it does $\frac{1}{5}$th of oxygen, 12 per cent. of its own volume of oxygen, must take up under a pressure of two atmospheres, twice as much, under three atmospheres three times as much, and, if agitated with pure oxygen, nearly five times as much.

So long as it is not proved, that the absorptive power of blood for oxygen gas does not vary with the pressure in this way, we must assume that the cause of its absorption by the blood is a chemical attraction, by the effect of which a chemical compound is formed in the blood. The experiments of Regnault and Reiset, in which animals breathed in an air much richer in oxygen than the atmosphere, and the circumstance, that at great heights, which like the each other. Carbonic acid is expelled, and oxygen taken up in its stead, when the air contains a certain proportion of oxygen; and on the contrary, when the air contains an excess of carbonic acid, oxygen is expelled. If both are present in a certain proportion, an equilibrium between them is established; the blood then undergoes no change, and the venous blood is not converted into arterial.

Moreover, if the quantity of oxygen that can be absorbed depend, according to a certain law, on the amount of the carbonic acid to be expelled, it is clear that the increase of the amount of oxygen in the air must be altogether without influence on the respiratory process. This remarkable fact has been satisfactorily ascertained by Regnault and Reiset in their admirable researches. They found that animals, living for twenty-two to twenty-four hours in an atmosphere containing twice or thrice as much oxygen as the air, experienced no kind of uneasiness; and that the products of respiration, in their quantity and relative proportion, were exactly the same as when the same animals lived in common air. These experiments, as well as those of Magnus, prove that the lungs are not the true seat of the *formation* of carbonic acid, and are not the true source of animal heat, like a fire-place; but that, in the arterial blood, a current of oxygen is conveyed throughout the body, which, in its passage

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great plateaux of central America, are inhabited, respiration goes on, just as at the level of the sea, prove, that the amount of oxygen absorbable by the blood is a constant value, and, to a certain degree, independent of the external pressure. In the neighbourhood of the Piticaco lake, 15,000 people live in the town of Puno, at a height of 12,000 feet above the sea. The city of Potosi, in Bolivia, at a height of 12,600 feet, has 30,000 inhabitants. In these countries the people inspire only about $\frac{2}{3}$ of the absolute quantity of oxygen which enters the lungs at each inspiration at the sea level, and it is evident, that if the amount of *absorbed* oxygen differed in the same ratio, this change must exert a marked and essential influence on the vital functions, such as could not have escaped observation.

through the minuter vessels, causes the formation of products of oxidation or combustion, among which is carbonic acid, and consequently gives rise to a disengagement of heat. The relation of dependence between the absorption of oxygen and the formation and expulsion of carbonic acid seems further to prove that both, in the blood, are conveyed and carried by the same means, namely, the blood corpuscules ; that these absorb oxygen in the lungs, and during the circulation give off that oxygen and take up the carbonic acid generated. From this it follows, that these corpuscules cannot take up more oxygen than they have given off carbonic acid, because the one gas takes the place of the other, and because the two cannot exist at one time in the same place, but mutually displace each other.

It is further evident, that the amount of carbonic acid in the air is one chief obstacle to the separation of that gas from the blood, and, therefore, an obstacle to the absorption of oxygen. When the amount of carbonic acid increases, the absorption of oxygen is impeded, even when its quantity remains the same. It is only by a corresponding addition of oxygen that this injurious effect of carbonic acid can be counteracted. Such an increase of oxygen never occurs under ordinary circumstances ; but Regnault and Reiset have observed, that animals could live in air containing one and a half to twice as much oxygen as common air, even if the amount of carbonic acid were so great as from 17 to 23 per cent., that is about four hundred times greater than in common air ; and this, without any injurious effect, after twenty-two to twenty-six hours. Such a proportion of carbonic acid in common air is absolutely incompatible with life.

The fact, that men and animals die very rapidly from inhaling pure carbonic acid, while they live comparatively much longer in nitrogen or in hydrogen gases, is explained by this—that in an atmosphere of carbonic acid the blood cannot give off any portion of that gas, but on the contrary absorbs more of it, by which the small proportion of oxygen in venous blood is expelled from the blood, and consequently its vital functions are much impeded, nay, arrested.

The condition most favourable to a rapid and perfect formation of arterial blood, and a more accelerated expulsion of carbonic acid from the venous blood is, consequently, a rapid change of air in the air-cells of the lungs.

When the inspired air has the same composition as that which is exhaled, the object of respiration is no longer attained. The expired air is used air, which cannot a second time perform the same function in the lungs. The venous blood is no longer changed into arterial; difficulty of breathing and, finally, suffocation, soon come on, just as if the mouth and nose had been closed.

In this case, death is determined by two causes. One is, beyond doubt, the deficiency of oxygen; the other is the presence of carbonic acid, by the presence of which the absorption of oxygen is impeded. In one of the experiments of Regnault and Reiset, a dog, three years old, in an atmosphere,—the amount of oxygen in which had fallen to 4½ per cent., while that of carbonic acid was 9¾ per cent.,—fell into death-like convulsions; but he soon recovered in pure air, and in half-an-hour was as lively as before. In these experiments, the carbonic acid given out from the lungs was for the most part removed, in the confined space in which the animal breathed, by solution of potash, introduced along with the animal.

If we reckon, in the state of rest, fifteen respirations per minute, and for each thirty-one cubic inches of air (English measure), and in the expired air 5 per cent. of carbonic acid, and 15 per cent. of oxygen, we easily find, that a man in twenty-four hours produces

540 litres or about 19 cubic feet (English measure) of carbonic acid, consuming in the same time 10,800 litres or about 380 cubic feet of air.*

In a closed space, eight feet high, nine long, and eight wide, a man could not breathe for twenty-four hours without uneasiness. At the end of that time the air would have the composition of expired air; and if the patient remained longer in the same air, a morbid state, and, finally, death would ensue. Lavoisier and Seguin found that the carbonic acid of expired air when again inspired, may be raised to 10 per cent., but not beyond that quantity, even when respiration was continued, which it could only be for a very short time. This proportion of carbonic acid may be regarded as the limit at which life is endangered in man.

Cases of this kind, in which death has been caused by the respiration of many persons in a confined space, too small for the abode of so many, are not rare. Every one has heard of the shocking results of the confinement of a number of prisoners in the Black Hole at Calcutta for one night, in the course of which most of them died. One of the most recent and lamentable accidents of this kind happened last year in an emigrant ship, in which, during a storm off the English coast, the emigrants were crowded into the cabin. In less than six hours more than sixty persons perished.

In a space in which many persons breathe, and in which the air is but imperfectly renewed through accidental chinks in doors and windows, the elongation of the flame of a candle, and its burning dimly, distinctly show the altered state af the air.

Even the very idea of respiring air, which has sojourned

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* According to experiment, these numbers may be regarded as the minima of production of carbonic acid and consumption of air. With 18 respirations per minute, the consumption of oxygen already rises by one-fifth.

for a time in the lungs of another, although of a healthy person, causes discomfort. It is certain that 1 per cent. of carbonic acid in the air produces a sensible uneasiness; and the advantage of a judiciously arranged renewal of the air, or ventilation, for all apartments, in which people remain together, is quite obvious.

For every adult there should be supplied to such an apartment at least 6 cubic metres, or 216 cubic feet (English) per hour, of pure air; in general about one-half more is reckoned upon. In the air of the Chamber of Deputies, at Paris, the hall of which has the cubical extent of 5000 cubic metres, Leblanc found that when 600 persons were present, and with a ventilation of 11,000 cubic metres per hour, the air flowing out contained, notwithstanding, 1 part of carbonic acid by weight in 400, which is 2½ or 3 times more than is contained in pure air.

In close places, in ships, many sick rooms and bed rooms, deficient ventilation might advantageously be compensated for by the use of hydrate of lime. The action of slaked lime depends on its great power of absorbing carbonic acid. In a room in which carbonic acid gas is present, the gas is very rapidly removed by slaked lime spread on a board. One cubic foot (Hessian, = 0·551, C. F. English) of it, which, when moist, weighs 18 or 20 lbs., and contains two-thirds of its weight of dry lime, absorbs, in order to be converted into carbonate of lime, more than 1100 litres, (70 Hessian, or 38·8 English cubic feet) of the gas. In the small closed space formerly described, if the carbonic acid formed were removed by means of a few pounds of slaked lime from the beginning, and its injurious effects thus avoided, a man would be able to live three or four times as long as without the lime.

Since such a space cannot be hermetically closed, the absorbed carbonic acid would be immediately replaced by an equal volume of fresh air, entering through the chinks.

The only inconvenience from the use of lime is, that as the lime combines with the acid, the water of the hydrated lime is set free, and partly evaporates, so that the confined man or animal soon breathes an air saturated with aqueous vapour. This inconvenience is well known to those who inhabit a newly built house. It appears during the first months, very strikingly in the winter months, in the form of an excess of moisture, which condenses in drops on the windows and cold walls. This is observed in houses which have been for years exposed to the action of dry air; and always for the first time when such houses are first inhabited. It does not proceed from ordinary moisture in the walls, but from the dry hydrate of lime in the mortar, which only gives out the twenty-four per cent. of water (which are chemically combined in it) *as moisture*, when the lime obtains a supply of carbonic acid to combine with it and displace the water. This supply is abundantly furnished by the lungs of those who inhabit the house.

The continuance of life, and the preservation of health, and of a due temperature in the body of man, stand in the closest relation to the respiratory process, the full efficiency of which depends on the constant composition of the atmospheric air. When this is altered, by any cause, temporarily or permanently, the influence of the alteration shows itself in a transient or permanent disturbance of the vital functions.

The living in low situations, in which the air is stagnant, in damp places, where carbonic acid is produced by decay, or in an air saturated with moisture at a high temperature, has long been recognised by physicians as the proximate cause of many diseases. In sleeping rooms, where plants grow, which during the night absorb oxygen and give out carbonic acid, in close rooms, in which combustion goes on,* the air

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* A cubic foot of coal gas consumes 2 to 2½ cubic feet of oxygen, and produces 1 to 2 cubic feet of carbonic acid.

acquires the composition of expired air, and the respiratory process is thus essentially endangered.

It has been pointed out, that in respiration, the amount of the expired carbonic acid, by volume, is not equal to that of the inspired oxygen, but a little smaller. But when carbon burns in a given volume of oxygen, converting it into carbonic acid, the volume of the gas undergoes no perceptible alteration. Carbonic acid contains its own volume of oxygen. If, therefore, the absorbed oxygen were employed only in producing carbonic acid, in the body, we should obtain a volume of carbonic acid equal to that of the oxygen consumed; whereas, the oxygen in the expired carbonic acid is rather less than the absorbed oxygen. The proportion between the two is very variable, and up to a certain point dependent on the food. With vegetable diet there is more, with a flesh diet much less oxygen exhaled in the form of carbonic acid. In the herbivora, the exhaled oxygen (as carbonic acid, the volume being the same) amounts to $\frac{8}{10}$ or $\frac{9}{10}$ of the inspired and absorbed oxygen; in the carnivora it is only ¾ of the whole. In starving animals, of either class, the proportion is the same, and is that of the carnivora, an evident proof, that in starvation the oxygen taken up into the blood combines, in the body, with the same substances; that is, respiration is carried on at the expense of the constituents of their bodies.

The question, as to what becomes of the 10 to 25 per cent. of oxygen, which seemingly disappears in respiration, is easily answered, if we consider, that the only combustible elements in the body are carbon, hydrogen, and a very small amount of sulphur. It cannot be doubted, that the greater part of that deficient oxygen, is consumed in forming water, by combining with the hydrogen. The disappearance of the fat, a body so rich in hydrogen, in starving persons, and that of the alcohol of spirituous liquors, furnish perfect evidence of this formation of water; and the fact, that marmots or dormice, in their winter sleep, lose weight by respiration, is thereby sufficiently explained. In that state, the animal drinks no water, but yet it passes from time to time, water in its urine, the separation of which, of course, produces a loss of weight, which bears a definite relation to the amount of oxygen absorbed and converted into carbonic acid and water.

We know exactly the amount of heat which is disengaged in the conversion of oxygen into carbonic acid and water. If we place a burning spirit-lamp under a tea-kettle filled with water, having weighed the lamp previously; if we extinguish it when the water begins to boil, that is, when every part of it has been heated to 212°, and again weigh the lamp, we find how much spirit has been used, or burned, to heat the water to its boiling point. And if we know the weight of the water, and its original temperature, we can very easily calculate how many degrees of heat a certain weight of spirit gives out in combining with oxygen. With a proper apparatus, where all the heat produced is conveyed without loss to the water, it has been in this way ascertained that one ounce of pure spirit can heat 69 ounces of water from the freezing to the boiling point. Every ounce of these 69 ounces has therefore received 100 degrees (Centigrade) of heat, and all together have received 69 times as much, or 6900 degrees. This number, 6900, may be taken to express the amount of heat produced by the combustion of one part by weight of spirit, and this in the form of degrees of heat gained by a known weight of water.

In the same way, the heat of combustion in carbon, hydrogen, coals, wood, and peat, &c., has been ascertained. The heat produced by coals is, on the same scale, 5625. With 1 lb. of coals we can heat 56¼ lbs. of water from 32° to 212°, or 562½ lbs. from any temperature, 10°, from 32° to 42°, or from 100° to 110°; or lastly, 5625 lbs. to the extent of 1°. The unit of heat is not an ordinary degree, but it is the amount of heat which a weight of water, equal to that of the burnt body, receives when its temperature is raised one degree of the centigrade scale.

The heat of combustion of pure carbon is greater than that of coals; according to Andrews, it is 7881; that of hydrogen is still higher, namely 33,808 units of heat. By the combustion of hydrogen water is formed; by that of carbon, carbonic acid is produced; and since water contains eight times the weight of oxygen that it does of hydrogen, while carbonic acid contains 2½ times the weight of oxygen that it does of carbon, one part, by weight, of oxygen, in its conversion into carbonic acid, yields 2950 units of heat, and in its conversion into water 4226 units of heat.

Consequently, if we know how much oxygen an animal consumes in twenty-four hours, and the quantity of carbonic acid and of water produced, the latter being known from the bulk of the oxygen which disappears as gas, it is easy to calculate the whole amount of heat which is produced by an animal in respiration. It is moreover easy to see that, when an animal is made to breathe in a proper apparatus, entirely surrounded with cold water, the number of degrees of heat given off by the animal in a definite time to the surrounding medium, may be easily determined. In this way it has been ascertained with certainty that the number of degrees of heat produced by an animal in the process of oxidation going on in its body, corresponds very closely to that which the same apparatus would receive, if it were heated by a fire, in which a quantity of oxygen, equal to that in the ascertained carbonic acid, and also to the portion of oxygen which has disappeared (as water) had been converted into the same quantities of carbonic acid and water. The question of the origin of animal heat is therefore satisfactorily solved.

LETTER XXVI.

In my last letter I endeavoured to give you some explanation of the functions, at once so simple and so wonderful, which oxygen performs in the animal economy. Allow me now to add some remarks on those substances which are designed to keep the mechanism of the system in action, namely the alimentary or nutritious matters.

If the growth or increase of mass in the animal body, the development of its organs and their reproduction, proceed from the blood, that is, the constituent parts of the blood, only those substances can serve these purposes which contain the elements of blood in a form and with qualities such that they can be converted or transformed into blood.

The blood contains 79 or 80 per cent of water, and 20 or 21 of solid matter, of which 1¼ to 1½ per cent. are incombustible, and remain after incineration as *blood ash.* The clot or coagulum consists of *blood corpuscules* enclosed in a network of *fibrine,* which latter body only amounts to 0·75 per cent. of the entire blood. The globules or corpuscules contain the *colouring matter* of the blood, distinguished by its never-failing and very considerable amount of iron. They contain further a substance identical with the chief solid constituent of the serum, namely *albumen,* to which is owing that the serum has all the properties of white of egg. Blood, or the serum of blood, coagulates when heated. The coagulating substance is the *albumen of the blood.*

One half of the ash of blood is *sea salt.* Besides this, there are found, originally in part dissolved in the serum, in part in chemical combination with the combustible constituents (fibrine, albumen, &c.), *lime, magnesia, potash, soda, phosphoric acid*, and *carbonic acid*. If we deduct the common salt or chloride of sodium, sesquioxide or peroxide of iron forms from 17 to 20 per cent. of the other half of the ash. Besides these substances, the blood contains also some fatty matters, several of which differ from ordinary fats in various properties.

The great importance of albumen to the vital animal process forces itself irresistibly on our notice, when we reflect on the development of the young animal in a fowl's egg. The albumen of the white and of the yolk in the egg, contains sulphur and nitrogen, as does the albumen of the blood. For every equivalent of nitrogen both kinds of albumen contain eight equivalents of carbon, and they agree also in the proportion of hydrogen. They are identical bodies, not only in properties, but, with the exception that the albumen of eggs contains a minute quantity of sulphur more than the other, in composition also.

We observe, in the next place, that in the impregnated egg, by the influence of heat, and by the aid of the oxygen of the air, which has access through the porous shell,—under the influence, therefore, of those conditions which accompany respiration, all the parts of the animal body, feathers, claws, fibrine, membranes, cells, blood corpuscules, the material of the blood-vessels and lymphatics, nerves and bones are developed. It is obvious that albumen is the foundation, the starting point of the whole series of peculiar tissues, which constitute those organs which are the seat of all vital actions. The elements of these organs, now possessing form and vitality, were originally elements of albumen. They are the products of certain changes which albumen has undergone, under the influence of heat and oxygen, in living organisms.

In the same way as in the egg, the albumen of the blood holds the first place in the process of formation of the fœtus, to which it is conveyed from without. By its elements it takes a share in all processes, it determines growth, and also the production and renewal of all organised tissues in the young as well as in the adult frame. Albumen is a constituent of the brain and of the nerves; of the liver, kidneys, spleen, pancreas, and of all glands.

Everywhere thoughout organised nature, where animal life is developed, we find the phenomena of life depending on the presence of albumen. The continuance of life is indissolubly connected with its presence in the blood, that is, in the nutrient fluid.

In so far as the notions of formation, nutrition, or the nutritive property are inseparable from that of a substance, whose properties and composition are collected in the word albumen; only those substances are in a strict sense, nutritious articles of food, which contain either albumen, or a substance capable of being converted into albumen.

If we look at alimentary substances from this point of view, we obtain a knowledge of a natural law of the most admirable simplicity.

The commonest observations teach us, that flesh possesses a greater nutritive power than all other kinds of food; the chief constituent of flesh is muscular fibre, or the fibrine of muscle, which constitutes nearly 70 per cent. of the dried flesh, purified from fat. In the flesh, this muscular substance is interwoven with fine membranes, and a multitude of nerves are ramified through it, as well as innumerable minute vessels, filled with coloured or colourless fluids.

Chemical analysis has detected the cause of the nutritive property of flesh, in a manner free from doubt, by showing that the fibrine of muscle and the albumen of blood contain the same elements in the same proportion; and that these two bodies stand to each other in the same relation as fresh albumen and coagulated albumen. In composition, fibrine is nothing more than albumen of blood solidified and in an organised form. The difference, if any, is so minute, that an analysis of the muscular fibre does not differ more from one of albumen of blood, than two analyses of the latter body do from each other (Annalen der Ch. und Pharm. LXXIII. 126). The blood, considered as a whole, has the same composition as flesh.

In flesh, therefore, we have one of the first conditions for the production of blood. In digestion, the muscular fibre, like boiled white of egg, becomes soluble and capable of entering the blood; and it would be almost pedantic, with our experience of the nutritive process in carnivora, to ask for proof that digested muscular fibre again acquires in the body all the characters of the albumen of blood. It would be, however, easy to supply this proof, since muscular fibre can be converted into albumen even out of the body, by a process, the ultimate cause of which we consider identical with that which effects the solution of food in the stomach. If we leave muscular fibre covered with water, and exposed to the influence of the air, a very small part of it passes into decomposition, and by the action of this the whole of the rest becomes liquid and soluble in water; the solution, when heated, coagulates to a white solid mass, which is identical in all its properties with the coagulated albumen of blood.

If we examine milk—that important alimentary substance which, prepared in the body of the mother, is supplied by nature to the body of the young animal for its development—we find in it, in the shape of *caseine*, a substance which contains, like albumen, sulphur and nitrogen; and the absence of every other nitrogenous compound in milk, renders it perfectly certain that from caseine alone the chief constituent of the young animal's blood, as well as its muscular fibres, membranes, &c., are formed in the first stage of its life.

Caseine is in its properties distinct from albumen and fibrine. It is held in solution in milk by an alkali, and may be heated to boiling without coagulation. Diluted acids, which do not coagulate albumen, easily separate the caseine from milk; it is easily coagulated in the cold by diluted acetic acid, and separates in the form of a jelly or of thick flocculent masses, which, after boiling with water, dissolve with extreme facility in weak alkaline liquids; a property by which caseine is very essentially distinguished from coagulated albumen and muscular fibre.

The analysis of caseine has proved that this body also contains the same elements and in the same proportion as albumen and fibrine, with the exception that it contains a little less sulphur. It is therefore plain that in the caseine of milk the young animal receives the fundamental constituent of its blood in a different form, one, however, the best adapted for the development of its organs.

We can now understand the nutrition of the carnivora and of the sucking young of mammalia. The carnivora live on the blood and flesh of those animals which live on grass and grain. This blood and flesh is in all respects identical with their own; the suckling receives its blood from the blood of its mother. In a chemical sense we may say that the carnivorous animal, to live, consumes itself, while the suckling consumes its mother. Its nourishment is, in its chief constituent, identical with the chief constituent of its blood from which its organs are developed.

The process of nutrition in graminivorous animals appears at first sight altogether different. Their digestive organs are less simple, and their food consists of vegetables which in form and quality have not the smallest resemblance to milk and flesh.

The question as to their nutritive properties was, in fact, not many years ago, an apparently insoluble enigma, and we now see how it was possible for the most acute and distinguished physicians to regard the stomach as the abode of a conjuror, who, if respectfully treated, and in good humour, can change thistles, hay, roots, fruits, and seeds, into blood and flesh; but when angry, despises or spoils the best food.

All these riddles have been solved with certainty. It has been proved that all such parts of plants as serve for food to animals, contain certain constituents easily distinguished from others by burning with the smell of burnt wool. It is found that animals require for their support less of any vegetable food in proportion as it is richer in these peculiar matters, and cannot be nourished by vegetables in which these matters are absent.

These important products of vegetation are especially abundant in the seeds of the different kinds of grain, and of peas, beans, and lentils; in the roots and the juices of what are commonly called vegetables. They exist, however, in all plants, without exception, and in every part of plants in larger or smaller quantity.

These nitrogenised forms of nutriment in the vegetable kingdom may be reduced to three substances, which are easily distinguished by their external characters.

When the newly-expressed juices of vegetables are allowed to stand, a separation takes place in a few minutes. A gelatinous precipitate, commonly of a green tinge, is deposited, and this, when acted on by liquids which remove the colouring matter, leaves a grayish white substance, well known to druggists as the deposit from vegetable juices. The juice of grasses is especially rich in this constituent, but it is most abundant in the seeds of wheat, and of the cerealia generally. It may be obtained from wheat flour by a mechanical operation, and in a state of tolerable purity ; it is then called *gluten*, but the glutinous property belongs, in part, to an oily substance, present in small quantity.

The second nitrogenised compound remains dissolved in the juice after the separation of the fibrine. It does not separate from the juice at the ordinary temperature, but is instantly coagulated when the liquid containing it is heated to the boiling point.

When the clarified juice of nutritious vegetables, such as cauliflower, asparagus, mangel-wurzel, or turnips, is made to boil, a coagulum is formed, which it is absolutely impossible to distinguish from the substance which separates as a coagulum, when the serum of blood, or the white of an egg, diluted with water, are heated to the boiling point.

The third of these important vegetable principles is chiefly found in the seeds of peas, beans, lentils, and similar leguminous seeds. It may be extracted from their meal by cold water and kept in solution. In this solution it resembles the others, but is distinguished from them in this, that its solution is not coagulated by heat. When the solution is heated or evaporated, a skin forms on its surface, and the addition of an acid causes a coagulum, just as in animal milk.

The analysis of these three vegetable principles has led to the interesting result, that they all three contain sulphur and nitrogen and the other constituents in the same proportion, and, what is still more remarkable, that they are identical in composition with albumen, containing the same elements, in the same proportion as that chief constituent of blood.

How admirably simple, after we have acquired a knowledge of this relation between plants and animals, appears to us the process of formation of the animal body, the origin of its blood and of its organs ! The vegetable substances, which serve for the production of blood, contain already the chief constituent of blood, ready formed, with all its elements. The nutritive power of vegetable food is directly proportional to the amount of these sanguigenous compounds in it; and in consuming such food, the herbivorous animal receives the very same substances which, in flesh, support the life of the carnivora.

From carbonic acid, water, and ammonia, that is, from the constituents of the atmosphere, with the addition of sulphur and of certain constituents of the crust of the earth, plants produce the blood of animals; for the carnivora consume, in the blood and flesh of the herbivora, strictly speaking, only the vegetable substances on which the latter have fed. These nitrogenised and sulphurised vegetable products, the albuminous or sanguigenous bodies, assume, in the stomach of the herbivora, the same form and properties as the fibrine of flesh and animal albumen do in the stomach of the carnivora. Animal food contains the nutritive constituents of plants, stored up in a concentrated form.

A comprehensive natural law connects the development of the organs of an animal, their growth and increase in bulk, with the reception of certain substances, essentially identical with the chief constituent of its blood. It is obvious that the animal organism produces its blood only in regard to the form of that fluid, and that nature has denied to it the power of creating blood out of any other substances, save such as are identical, in all essential points, with albumen, the chief constituent of blood.

The animal body is a higher organism, the development of which begins with those substances, with the production of which the life of those vegetables ends, which are commonly used for food. The various kinds of grain and of plants used for fodder, die as soon as they have produced seeds. Even in perennial plants, a period of their existence terminates with the production of their fruit. In the infinite series of organic products which begins with the inorganic food of plants, and extends to the most complex constituents of the nervous system and brain of animals the highest in the scale, we see no blank, no interruption. The nutritive part of the food of animals, that from which the chief material of their blood is formed, is the last product of the productive energy of vegetables.

If we compare the three nitrogeno-sulphurised vegetable products with the fibrine of flesh, the albumen of blood, and the caseine of milk, on reference to their physical characters, we find that the gluten of wheat-flour has the closest resemblance to the fibrine of flesh; that that constituent of vegetable juices which is coagulated by heat, is absolutely not distinguishable from the albumen of blood; and lastly, that the chief constituent of the seeds of the Leguminosæ agrees in all its properties and behaviour with the caseine of milk. Hence are derived the names of *vegetable fibrine*, *vegetable albumen*, and *vegetable caseine*,* which have been most justly given to these three vegetable products, since they perfectly agree in properties with the corresponding animal products.

The three nitrogeno-sulphurised or sanguigenous constituents of seeds and vegetable juices are never, or at least very rarely indeed found alone. Thus, in the juice of potatoes there is found, besides fibrine and albumen, vegetable caseine coagulable by acids; and in the seeds of Leguminosæ there is always, besides the caseine, a certain quantity of albumen coagulable by heat. The so-called gluten of rye meal consists almost entirely of vegetable caseine and vegetable albumen. In wheat flour all three are found.

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* A remarkable proof of the true nature of vegetable caseine is furnished by a fact, quite independent of chemical researches, which is recorded by J. Itier in his report. The Chinese, it appears, are

It is worthy of special remark, that animal fibrine and vegetable fibrine, animal albumen and vegetable albumen, animal caseine and vegetable casine, not only contain respectively the same elements in the same proportions, but also possess like properties. The gluten of wheat-flour, (which consists chiefly of fibrine), dissolves almost entirely to a turbid fluid, in water to which hydrochloric acid has been added in the proportion of a drop to each ounce. In this solution, just as in that obtained from flesh in the same way, sea-salt causes coagulation. The coagulum, covered with pure water, and left to putrefy, dissolves almost entirely to a clear fluid, and this occurs equally with the fibrine of flesh. Here the putrefaction of a small portion has caused the solution of the remainder, and in both cases the solution is now found to contain a large quantity of true albumen, coagulable by heat.

Lastly. These different substances, whether of animal or vegetable origin, yield, in processes of oxidation, the same products ; a fact which chemistry regards as a proof that their elements are also arranged in the same way. These products are sufficiently remarkable to justify us in directing attention to them. When such compounds are acted on by strong potash, a part of their sulphur is taken up by the potash, and the alkaline solution, by the presence of sulphuret of potassium, acquires the property of forming when a drop of solution of sugar of lead is added, an inky fluid, coloured by the sulphuret of lead. The further action of the alkali produces from all

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in the habit of making a real cheese from peas. For this purpose, the peas are boiled to a thin paste, which is passed through a sieve, and coagulated by the addition of solution of gypsum. The curd is treated like that formed in milk by means of rennet. The solid part is pressed out, and, with the addition of salt, is wrought into cheese in moulds. This cheese gradually acquires the smell and taste of milk cheese. It is sold in the streets of Canton, under the name of Taofoo, and, when fresh, is a favourite article of food with the people.

these sanguigenous compounds two crystalline products, allied to the organic bases, namely, *Tyrosine* and *Leucine*, the latter of which Prout first found in putrid cheese, and Crum in putrescent gluten; and which acquires now a greater importance, since, besides its occurrence as a product of the oxidation as well as of the putrefaction of these substances out of the body, it, Leucine, has lately been detected ready formed in the body, namely, in the fluids of the liver of the calf. Besides these crystallised products, there are formed by the action of alkalies on sanguigenous substances several volatile oily acids, such as Butyric and Valerianic acids. When the oxidation is conducted in acid liquids, we obtain numerous and very remarkable products, among which are Hydrocyanic acid, Oil of bitter almonds (hyduret of benzoyle), Benzoic acid, Formic, Acetic, Propylic, Butyric, and Valerianic acids, as well as several of the corresponding Aldehydes; so that probably no other organic substances can in this respect be compared to the sanguigenous bodies, animal or vegetable.

The consideration that vegetable albumen, vegetable fibrine, vegetable caseine, animal fibrine, and animal caseine, are the only nutritive matters in the animal or vegetable kingdoms, from which, in the process of nutrition, the chief constituent of the blood, and, in the vital process, all the tissues of the animal body are formed, has led chemists and physiologists to give to these five nitrogeno-sulphurised substances, to which may be added the albumen of the blood, since, as an element of the animal body, it becomes a nutritive article of food, the name of *plastic elements of nutrition*. (This is to be considered as synonymous with the shorter and more convenient term of *sanguigenous bodies*, which I have occasionally used above, as well as with the terms *nitrogeno-sulphurised*, *azoto-sulphurised*, and *albuminous* bodies, which are also frequently used.—W. G.)

There is, indeed, no part of an organ, possessing a form or structure of its own, the elements of which are not derived from the albumen of the blood. All organised tissues in the body contain a certain amount of nitrogen.

Many of the physical properties of the organs or tissues depend on the presence of their non-nitrogenous constituents, namely, of *water* and *fat*. These bodies assist in the changes and processes, by which organised structures are formed. Fat has a share in the formation of cells; and on water depends the fluidity of the blood and of all other juices. So also the milk-white colour of cartilage, the transparency of the cornea, the softness, plasticity, flexibility, and elasticity of muscular fibre and of membranes, the silky lustre of fasciæ and tendons; all depend on a fixed proportion of water in each case. Fat is a never-failing constituent of the substance of the brain and nerves; hair, horn, claws, teeth, and bones, always contain a certain amount of water and fat. But in these parts water and fat are only mechanically absorbed, as in a sponge, or enclosed in drops, as fat is in cells, and they may be removed by mechanical pressure, or by solvents, without in the least affecting the structure of the parts. They never have an organised form peculiar to themselves, but always take that of the parts, the pores of which they fill. They do not belong, therefore, to the plastic constituents of the body or of the food.

LETTER XXVII.

THE food of all animals, besides the plastic or sanguigenous constituents, from which the blood and the organs are derived, contains, at all times, and under all circumstances, a certain amount of substances devoid of nitrogen and of sulphur.

Flesh, the food of the carnivora, contains a certain quantity of fat; milk contains fat (in butter), and along with this an easily crystallisable body, sugar of milk, which is obtained from the whey of sweet milk by evaporation. The food of the herbivora always contains a substance resembling sugar of milk, and closely allied to it in chemical characters. (Starch, cane and grape sugar, gum, &c.)

The properties of milk-sugar, considered as a constituent of milk, and as a product of the vital process in animals, are peculiarly interesting. Hitherto this kind of sugar has been found only in milk, and, according to recent researches, although in very small proportion, in eggs. It occurs in commerce in thick crystalline crusts, which are usually yellowish, yellowish-brown, or dirty, from want of care and cleanliness in its preparation. By recrystallisation, and the use of animal charcoal, to decolorise the solution, it is obtained in four-sided prisms, acuminated by four planes, which are dazzling white, hard, and gritty in the teeth.

Crystallised milk-sugar dissolves in five or six parts of cold water, without forming a syrup; the crystals, placed on the tongue, have a weak sweet taste, which is stronger in the solution. The property of fermenting, when left to itself at a moderate temperature, which milk possesses, depends on the presence of milk-sugar. Fermented milk yields, when distilled, true brandy, which has, however, an offensive smell of butyric acid and rotten cheese. This spirit, prepared from mare's milk, is in general use in Tartary and in the country of the Khirgeses and Kalmuks. The facility with which under certain circumstances, milk-sugar undergoes another transformation, and is converted into lactic acid, is well known to every one from the fact that milk so readily turns sour.

Milk-sugar is distinguished by the power of absorbing oxygen when free alkali is present. If a solution of it be rendered alkaline by means of ammonia, and a salt of silver added, the oxide of silver, when the solution is warmed is reduced, either as mirror-like deposit on the glass, or in grey flocculi. A solution of milk-sugar to which potash is added, dissolves oxide of copper, with a beautiful blue colour. This solution, when heated, becomes of a fine red, the copper separating as red suboxide. In these instances the oxygen of the oxides is taken up by the elements of the milk-sugar, entirely in the case of silver, and to the extent of one-half in that of copper.

An alkaline solution of milk-sugar dissolves peroxide of iron and other oxides, and the same solution decolorises blue indigo, which is dissolved in the colourless or deoxidised form, yielding a true indigo bath, fit for dyeing.

By the influence of many ferments, and with the greatest facility in presence of lime, the lactic acid derived from milk-sugar is converted into butyric acid, which belongs to the group of fatty or oily acids. When oxidised by means of nitric acid, milk-sugar yields carbonic, oxalic, and mucic acids.

Finally, if to a solution of milk-sugar in water we add some sulphuric acid, the milk-sugar is very rapidly converted into grape-sugar.

Crystallised milk-sugar contains carbon and the elements of water, oxygen, and hydrogen, in such proportions that if we suppose the whole of its hydrogen replaced by the equivalent quantity of oxygen, the result will be carbonic acid. If we represent milk-sugar by the formula $C_{12}\ H_{12}\ O_{12}$, and replace the 12 eqs. of hydrogen by 12 eqs. of oxygen, we have $C_{12}\ O_{12}\ O_{12}$ or $C_{12}\ O_{24}$, which is $= 12\ C\ O_2$; that is, 12 eqs. of carbonic acid.

Sweet fruits and sweet vegetable juices owe their sweet taste to three kinds of sugar, of which two are crystallisable, while the third is always soft or of syrupy consistence. This last kind occurs in most fruits. (Mitscherlich.) Beet-root and carrots contain the same kind of sugar as the juice of the sugar-cane; honey contains the same kind as grapes. Of these sugars, grape-sugar, in its character and composition, most resembles milk-sugar. Dried grape-sugar has the same composition as crystallised milk-sugar; and in its action on metallic oxides, such as oxide of silver, oxide of copper, and peroxide of iron, and on indigo, as well as in the property of passing under certain circumstances into lactic and butyric acids, it agrees exactly with milk-sugar.

Cane-sugar differs from crystallised milk-sugar and from dried grape-sugar in composition only by the elements of 1 eq. of water, its formula being $C_{12}\ H_{11}\ O_{11}$; but by contact with ferments or acids, it takes up into its composition this 1 eq. of water, and passes with great facility into grape-sugar.

The most universally diffused substance in the vegetable kingdom and in the food of herbivora, which in the process of their nutrition plays the same important part as milk-sugar does in that of carnivora, is starch, which appears at first sight the most remote from milk-sugar in its properties.

Starch is found deposited in rounded grains in the seeds of the cereals and leguminosæ, in roots and tubers, and in wood, and after breaking up the cells which enclose it, may be obtained by washing with water. If potatoes, unripe apples or pears, chestnuts, acorns, radishes, arrow-root, the pith of certain palms, wheat, and other grains, be rubbed down, and the paste washed with water on a fine sieve, the white and turbid fluid which passes through deposits starch in the form of a snow-white very fine powder. It occurs in commerce in various forms. The finest starch from wheat is known as hair powder; sago is the starch of the sago palms, granulated and dried as well as slightly baked together by heat; arrowroot is that of the plant of that name, *Maranta arundinacea;* mandiocca is that of *Iatropha Manihot* (the three last kinds, as sold on the continent, are chiefly potato starch). All kinds of starch have the same composition and the same chemical characters; except the peculiar starch (inuline) of *Inula helenium*, of the dahlia-root, and many lichens; all give with hot water a more or less fluid or gelatinous paste, which strikes a splendid indigo blue colour with solution of iodine.

It has already been mentioned, in Letter XVI., that starch, by the influence of the gluten of grain in the germination of corn, or by that of sulphuric acid, is converted into grape-sugar.

When mixed with a hot infusion of malt, starch-paste or jelly becomes at once fluid; there is at first formed a substance like gum, known as starch-gum or dextrine, which, by the continued action of the malt, is entirely changed into grape-sugar. A precisely similar action is exerted on starch-jelly by saliva including air. A mixture of saliva with starch-paste, exposed to the temperature of the human body, becomes more fluid and sweet, and, by means of a proper quantity of saliva, the whole starch is transformed into grape-sugar.

The difference in external form and characters between starch and grape-sugar is thus, it is easy to see, almost entirely destroyed in the digestive process. Nature has so arranged it, that, during mastication, there is added to amylaceous food a substance, by the action of which in the stomach, the starch is transformed into a substance which agrees in its composition and in its chief properties with sugar of milk.

The amount of starch in the flour of different kinds of grain, in peas, beans, lentils, and potatoes, is very large. Wheat and rye-flour contain from 60 to 66; barley and lentils, 40 to 50; maize-flour about 78; rice as much as 86; potatoes (dry) above 70 per cent. of starch.

The fat of butter and that of flesh contain carbon and hydrogen very nearly in the same relative proportion as starch and the various sugars; these differ from fat chiefly in containing more oxygen. For the same quantity of carbon, fat contains nearly ten times less oxygen than starch, &c.; and it is therefore easy, by adding oxygen, to convert, in our calculations, a given amount of fat into starch. In this way we find that ten parts of fat correspond to twenty-four of starch. In like manner, by deducting a certain amount of water, we can reduce milk-sugar to its equivalent of starch; and, by thus reducing all the non-nitrogenous elements of food to their equivalent values expressed as starch, we can readily compare the most important articles of food in regard to the proportions of plastic or sanguigenous, and of non-nitrogenous substances which they contain. This is done in the following table:—

Relative Proportions of the Plastic to the Non-nitrogenous constituents in different articles of food.

	Plastic.	Non-Nitrogenous (as Starch).
Cow's Milk contains, for	10	30 = { 8·8 fat, 10·4 milk-sugar.
Human Milk „	10	40
Lentils „	10	21
Horse Beans „	10	22
Peas „	10	23
Fat Mutton „	10	27 = 11·25 fat.
Fat Pork „	10	30 = 12·5 „
Beef „	10	17 = 7·08 „
Hare „	10	2 = 0·83 „
Veal „	10	1 = 0·41 „
Wheat Flour „	10	46
Oatmeal „	10	50
Rye Flour „	10	57
Barley „	10	57
Potatoes, white „	10	86
„ blue „	10	115
Rice „	10	123
Buckwheat Flour „	10	130

The relative proportions of the plastic constituents in milk to its butter and milk-sugar, that of the sanguigenous matter in flesh to its fat, and that of the plastic matter of grain, potatoes, and the seeds of the leguminosæ, to their starch, are not constant. They vary in milk with the food; fat or fattened flesh contains more fat than that which is lean; and the difference between the two kinds of potato shows how great may be the variation in different varieties of the same plant. But the above numbers may be regarded as average numbers, lying between the opposite extremes in each case. We may regard as constant the following results; namely, that peas, beans, and lentils contain, for 1 part by weight of plastic matter between 2 and 3 of non-nitrogenous matter, reckoned as starch; that grain, such as wheat, rye, barley, and oats contain between 5 and 6 parts; potatoes, from 8 to 11 parts; rice and buckwheat, from 12 to 13 parts of the latter to 1 of the former. Of all food, lean flesh is richest in plastic constituents. Omitting the inorganic constituents, 17 parts of lean beef contain as much plastic or sanguigenous matter as 56 parts of wheat-flour, or 67 of rye-flour, or 96 of white potatoes, or 133 of rice.

In comparing these kinds of food, we must bear in mind, that in their natural state they all contain a certain amount of water, which must be taken into account ; 17 parts of dry beef, containing 7·08 parts of fat, contain, in the natural state, 32 parts of water. As wheat-flour contains 15 per cent. of water, the 49 parts (17 + 32) of fresh beef correspond to 66 parts of flour.

It is obvious, that by a due mixture of these articles of food, we can obtain a diet of a composition analogous to that of milk or of wheaten bread. By the addition of bacon or fat fork to peas, beans, or lentils ; of potatoes to beef ; of fat bacon or ham to veal ; of rice to mutton ; we increase in each case the proportion of non-nitrogenous matter. The same result is obtained by the use of fermented liquors, which, when taken with lean flesh and little bread, yield a diet approaching to milk, and, with fat meat, one approaching to rice or potatoes, in the relative proportions of plastic and non-nitrogenous constituents.

A glance at these relations is sufficient to convince us, that, in choosing his food (when a choice is open to him), and in mixing the various articles of diet, man is guided by an unerring instinct, which rests on a law of nature.

This law prescribes to man, as well as to animals, a proportion between the plastic and non-nitrogenous constituents of his whole diet, which is fixed within certain limits, within which it may vary, according to his mode of life and state of body. This proportion may, in opposition to the law of nature and instinct, be altered beyond these limits by necessity or compulsion ; but this can never happen without endangering the health, and injuring the bodily and mental powers of man.

It is the elevated mission of science to bring this law of nature home to our minds; it is her duty to show why man and animals require such an admixture in the constituents of their food for the support of the vital functions, and what the influences are which determine, in accordance with the natural law, changes in this admixture.

The knowledge of this law elevates man, in regard to an important function which he possesses in common with the lower animals, above the level of those beings which are destitute of reason, and supplies him, in the regulation of those bodily wants which are essential to his existence and prosperity, with a protection, which the lower animals do not require, because in them the commands of the instinctive law are not opposed or overpowered by the allurements of sense nor by a perverted and resisting will.

The inquiry as to the ultimate foundations on which this law of instinct rests, which compels men and animals to consume, along with the plastic matters from which their organs are formed, certain non-nitrogenous bodies, which take no direct share, by their elements, in the formation of these organs, and the further inquiry as to the part which these substances perform in the vital process, are easily answered when we compare the constituents of the body with those of the food, and consider the latter as the causes or conditions of those effects which they produce in the living body.

A working horse consumes, in a year, 5,475 pounds of hay, and 1,642 pounds of oats.* An adult pig, weighing 120 pounds, consumes, in the same time, 5,110 pounds of potatoes.† With this prodigious

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* Ann. de Chim. et de Phys., LXXI., 136.

† Ann. de Chim. et de Phys., Nouvelle Serie., XIV., 443.

mass of food, which, in the pig, amounts to more than forty times the weight of its body, the weight of these animals, at the year's end, either does not increase, or the increase is a mere fraction of the weight of the food.

So it is with the food of man. In an adult, whose weight is not perceptibly altered at the year's end, the proportion of the parts and their composition are the same as at the beginning of the period. The whole quantity of food taken in 365 days, has not been employed in increasing the size or weight of his body, but has only served to produce a series of effects.

The fourteen pounds of potatoes, daily consumed by the pig, produced in its body a certain quantity of mechanical force, by which the motion of its blood, of its juices, and of its limbs was effected. The constituents of the food served to keep the mechanism in action.

A result precisely similar was effected by the fourteen pounds of hay and the four and a half pounds of oats, daily consumed by the horse; with this difference, however, that this amount of food enabled the horse to expend a certain amount of mechanical force externally. The food produced in his body an excess of force, by which his limbs were enabled, without injury to health, to overcome a certain sum of resistance, that is, to perform a certain amount of work.

In the body of the man, the bread, flesh, and vegetables produced the same effect as in the horse; but, in addition to the mechanical force, which determined the involuntary motions of his internal organs and the voluntary motions of his muscles in his work, the food also produced a certain sum of effects, manifested in the action of the senses and of the intellect.

We know that when food is withheld, the body of man and of all animals loses weight every second; that the decrease or loss in the most important organs in a given time, stands in a certain ratio to the manifestations of force produced, in the same time, by his organs or his limbs; that by the food, the weight of the body, and the power of producing new manifestations of force, is restored; that in a state of rest, man and animals require less food than in that of motion or exertion; and that it is not a matter of indifference what is the quality of the food which the man or beast must daily consume, in order to recover, undiminished, the original power, and to perform, on the following day, the same amount of work as on the first, or to produce the same manifestations of force through the nervous system, or mental manifestations.

Innumerable observations, made during centuries, have demonstrated beyond a doubt, that different forms of food are extremely unequal in regard to the production and restoration of these powers or forces; that wheat surpasses rye, that rye surpasses potatoes and rice, and that flesh surpasses all other food in reference to these effects. These observations, made by all mankind, have shown, that a horse, fed on potatoes, cannot perform anything like the same amount of work as one fed on hay and oats; and, lastly, that the power of daily labour, available in man, may be measured by the quantity of the plastic or sanguigenous constituents contained in the flesh and bread he consumes.*

It is obvious, that the plastic constituents of food are the proximate conditions or causes of the production of force in the organism, and of all mental

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* The daily ration in bread, given to a soldier, is, in

	Grammes.	
France . . .	750	(Wheat).
Belgium . . .	775	„
Sardinia . .	737	„
Spain . . .	670	„
South Germany .	900	($\frac{1}{6}$ Wheat, $\frac{4}{6}$ Rye, $\frac{1}{6}$ Barley.)
North Germany .	1000	(Rye.)

The gramme is 15·44 grains, 1000 grammes is equal to about 2 lbs. 3¼ oz. avoirdupois, 750 grammes are equal to 1 lb. 10½ oz.

manifestations, such as those of sense, emotion, or intellect.

We can readily understand this, when we reflect that all the phenomena of motion in the animal organism, all the effects which an animal produces by its brain or its muscles, are determined by, or depend on the organised structure of his body; that the unorganised parts, which have no form, such as water and fat, have no vital properties, and cannot change their place or relative position by any power inherent in themselves.

But if the effects producible on the body of a man or beast, whether in his organs of sense, his brain, or the organs of the voluntary and involuntary motions, depend on the number or size of the organised parts, it is evident that the amount or the duration of these effects must be in proportion to the mass of the individual parts of which the organs consist; the cerebral manifestations must be in proportion to the mass of the brain, the mechanical effects to the mass of muscular substance.

With the decrease of the mechanical apparatus for the production and external manifestation of force, with the wasting of the substance of the muscles and nerves, the power of making such manifestations diminishes; with the renovation and restoration of these organised structures or tissues in the process of nutrition, the power of producing repeatedly the same manifestations of force, of performing the same mental or bodily labour, is regained.

All these organised tissues, all the parts, which in any way manifest force in the body, are derived from the albumen of the blood; all the albumen of the blood is derived from the plastic or sanguigenous constituents of the food, whether animal or vegetable. It is clear, therefore, that the plastic constituents of food, the ultimate source of which is the vegetable kingdom, are the conditions essential to all production or manifestation of force, to all those effects which the animal organism produces by means of its organs of sense, thought, and motion.

In this relation, in this dependence of the animal on the vegetable kingdom, a new and admirable connection is unfolded to the human mind.

Plants, which serve as food to animals, are the producers of the plastic constituents of food, and hence are accumulators of force. In repose and in sleep, animals return to the condition of plants; the formless constituents of their blood become organised portions of their tissues; and while these tissues, in their turn, are resolved in the vital process into formless or into inorganic compounds, the force stored up in them is manifested in the most various effects; like a galvanic battery, the peculiar properties of which are determined by a certain arrangement of its elements, and which consumes itself in giving rise to new manifestations, magnetic, electrical, or chemical.

The relations of the plastic constituents of food to the vital process in the animal body, appear thus to be cleared up. These substances, restoring the original weight of the organised tissues, part of which has been consumed, and has been separated, render possible the continued manifestation of all vital actions.

A horse, fed on potatoes, and compelled to work, loses weight; when he does no work, his weight remains unchanged. It is obvious that the work performed consisted in a waste or consumption of bodily parts; and the quantity of plastic substances present in the whole amount of potatoes consumed did not suffice for the full restoration of the wasted tissues. More was consumed than the food given could replace, and hence the animal began to show signs of emaciation and weakness.

On the other hand, the horse, which is abundantly fed with hay and oats, can perform a certain amount of labour, without any loss of weight being next day perceptible. When the same amount of food is given to the animal in a state of rest, it becomes heavier, increasing in weight up to a certain point. It is plain that the food produces in the body of the horse a certain sum of force, which may be employed either within the body itself, or in overcoming external resistance. If this force be used in the performance of work, the weight of the body remains unchanged; but if employed within the organism for vital purposes, the body increases in bulk in all its parts.

It follows from this, that the working power of an animal stands in a fixed ratio to the excess of food, which, in the state of rest, increases the weight of the body.

If our interpretation of this eternal and immutable law of nature be not false, the proportion of the plastic constituents, required by the working man in his daily food, cannot be less than that which nature herself prepares for the development and growth of the human body and for its increase in all its parts. Such is the proportion found in human milk. The diet of the working man should therefore contain, for four parts of non-nitrogenous constituents, one part of plastic nutritive matter.

This, indeed, is saying no more than is well known, since the world and its inhabitants have existed, that the man who has to do that amount of work which, according to the conditions of his organism he can perform, must add to his bread a certain amount of flesh; that according to the structure of his body the proportion of the plastic to the other constituents of the food must be increased, if he has to do more than average work; and that, in the state of rest he requires a smaller proportion of plastic nourishment.

It follows further, that when a child, deprived of the benefit of receiving the necessary supply from the mother, is fed on cow's milk, which contains a larger proportion of plastic matter, milk-sugar (or cane-sugar) should be added to the cow's milk; or when it is fed on flour paste, cow's milk should be added, as experience has long ago taught us, in order to obtain the same effects as from the mother's milk.*

It is further obvious, as indeed every one knows to be the case, that, if a child or young person be compelled by circumstances to expend in work external to the body, a part of the force produced in the organism, and if this excess of expenditure be not compensated by proper food, or cannot be compensated, because his body can only digest a certain quantity of food, his bodily development must be deranged and impeded.

The admirable experiments of Boussingault prove, that the increase in the weight of the body in the fattening or feeding of stock (just as is the case with the supply of milk obtained from milch cows), is in proportion to the amount of plastic constituents in the daily supply of fodder. These experiments were carried on for months with pigs, animals possessing in a high degree the power of converting the elements of their food into parts of their body. A pig was fed exclusively on potatoes, under which feeding it did not increase in weight; but an increase in weight was observed when the animal got a diet composed of potatoes, butter-milk, whey, and kitchen refuse. The greatest increase took place when the food was what was called fattening fodder, consisting daily of potatoes (9·74 lb.); ground corn (0·90 lb.); rye flour (0·64 lb.); peas (0·68 lb.); butter-milk, whey, and kitchen refuse (0·92 lb.)

Analysis and calculation show that the pig received,

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* According to a calculation by Knapp, a soldier, on the rations mentioned at p. 365, consumes, in his daily food, for 10 parts of plastic, 47 parts of non-nitrogenous matter.

in these three modes of feeding, food of the following proportions of the plastic to the other constituents.*

Proportion of the plastic to the non-nitrogenous constituents, the latter calculated as starch.

The pig consumed.	Plastic.	Non-nitrogenous.
In potato fodder, for . .	10	87
In mixed fodder, for . . .	10	71
In fattening fodder, for .	10	55

It is easy to see, that this last mixture contains the same proportion of plastic and non-nitrogenous matters as is found, on an average, in grain.

German agriculture has been led by experience to a very simple method of converting potatoes into a fattening fodder quite similar to the above-mentioned, and to grain in its composition. This method is the foundation stone of the profitable agriculture of Germany; and it consists in removing, entirely or to a great extent, and by a purely chemical process, the non-nitrogenous part of the potatoes, and using the residue, which contains all their plastic constituents, to feed stock. The potatoes are reduced to a thin paste, and placed in contact with malt, by the action of which the starch is converted into sugar. The mash, as it is called, is now mixed with beer yeast, which causes it to ferment, and the whole sugar is thus destroyed. By distilling the fermented mash, the starch of the potatoes is obtained in the form of spirits, and the residue or dregs forms the most valued food for fattening stock.

The opinion prevalent in other countries, that the German farmer is a distiller, for the sake of the spirits, is decidedly erroneous. He distils spirits, in order to obtain, at the cheapest rate, the fodder which is indispensable to him.

This method of concentrating the plastic matter, proper for the production of blood and flesh, is one

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* Ann. de Chim. et de Phys., Nouvelle Série, XIV., 419.

of the numerous instances in which empirical experiment has preceded theory. At first, the only object was to obtain the spirits; then it became desirable to make a profitable use of the residue; and finally, it was found, that the property of serving as fattening food was increased in potatoes, by the process of mashing and fermentation. As far as regards the propagation of this kind of truths, want and necessity are teachers, whose influence and power of convincing men are mightier than all science.

From what has been said, we can deduce in a manner free from doubt, the true significance of the plastic constituents of food. Becoming organised parts of the living body, they determine the continuance of all vital phenomena.

If we now consider, that the animal body is not merely a source of mechanical power and of vital actions, but also an apparatus for producing heat; that the amount of heat daily produced in the body of an adult man would suffice, in the course of a year, to heat from twenty to twenty-five thousand pounds of water from the freezing to the boiling point; if we bear in mind, that the animal heat is a result of the combination, in the body, of the oxygen taken up in respiration, with certain constituents of the food or of the body; and that the daily amount of heat produced is in direct proportion to the amount of oxygen consumed; the most superficial observation teaches us, that the elements of the plastic constituents of food can have only a very secondary share in the production of that heat, thus daily produced.

In fact, if we compare the amount of the plastic matters daily consumed with that of the oxygen consumed in the same time, we find that the combustible elements of the former are very far from sufficing to convert into carbonic acid and water the whole of the oxygen which has entered the blood. The animal body takes up far more oxygen; the horse, for example five times, the pig six times, as much as would be required for the most perfect combustion of the plastic matter in the food.

If, therefore, the combustible elements of the plastic constituents of food served for the production of heat, the whole amount of these substances consumed by the horse in his hay and oats, by the pig in its potatoes, would only suffice to support their respiratory process, and consequently their animal heat, in the horse for 4½ hours, in the pig for 4 hours daily; or, if confined to plastic food, they would require to consume five or six times as much of it.

But even in this last case, it is exceedingly doubtful whether these substances, considering their properties, would, in the circumstances under which they are presented to oxygen in the organism, produce the necessary temperature of the body, and compensate for the loss of heat; for of all organic compounds, the plastic constituents of food are those which possess in the lowest degree the properties of combustibility and of developing heat by their oxidation.

Of all the elements of the animal body, nitrogen has the feeblest attraction for oxygen; and, what is still more remarkable, it deprives all combustible elements, with which it combines, to a greater or less extent, of the power of combining with oxygen, that is, of undergoing combustion.

Every one knows the extreme combustibility of phosphorus and of hydrogen; but by combining with nitrogen they produce compounds entirely destitute of combustibility and inflammability under the usual circumstances. Phosphorus takes fire at the heat of the body, and is easily oxidised by dilute nitric acid. The phosphuret of nitrogen, a white body, like chalk, only takes fire at a red heat, and in oxygen gas, but does not continue to burn, and is not attacked by dilute nitric acid. Ammonia, a compound of nitrogen with hydrogen, contains, in two volumes, three volumes of hydrogen; but in spite of this large proportion of an element so inflammable and combustible, ammonia cannot be set fire to by a red hot body, and even in pure oxygen, it does not continue to burn. Almost all compounds of nitrogen are, compared with other bodies, difficultly combustible, and are never regarded as fuel, because when they do burn, they develope only a low degree of heat, not sufficient to raise the adjacent parts to the kindling point. Only cyanogen, which contains much carbon, and hydrocyanic acid, among compounds of nitrogen, may be set fire to in the gaseous form, and continues to burn when kindled.

It is precisely so with albumen in the alkaline blood. If we compare its power of combining with oxygen with that possessed by the non-nitrogenous bodies, milk-sugar, grape-sugar or fat, it has much the same relation to them as silver has to iron; and if we would divide the elements of the body, according to their combustibility, like the metals, into the classes of common and noble, then the organised structures of the body consist of the noblest substances found in organic nature.

Wherever it is vouchsafed to the feeble senses of man to cast a glance into the depths of creation, he is compelled to acknowledge the greatness and wisdom of the Creator of the world. The greatest miracle which he is capable of comprehending is that of the infinite simplicity of the means, by the co-operation of which, order is preserved in the universe as well as in the organism, and the life and continued existence of organised beings are secured. Without the powerful resistance, which the nitrogenised constituents of the body, in consequence of their peculiar nature as compounds of nitrogen, oppose, beyond all other parts, to the action of the air, organic life could not subsist.

If the albumen of the blood, which is derived from the plastic portion of the food, possessed in a higher degree the power of supporting respiration, it would be utterly unfit for the process of nutrition. Were albumen as such, destructible or liable to be altered, in the circulation, by the inhaled oxygen, the relatively small quantity of it, daily supplied to the blood by the digestive organs, would quickly disappear; and the slightest disturbance of the digestive function would of necessity put an end to life.

As long as the blood contains, besides albumen, other substances, which surpass it in attraction for oxygen, so long will the oxygen be unable to exert a destructive action on this, the chief constituent of the blood; and the significance of the non-nitrogenous part of the food is thus made clear.

Starch, sugar, and fat, serve to protect the organised tissues, and, in consequence of the combination of their elements with oxygen, to keep up the temperature of the body.

The sulphurised and nitrogenous constituents of food determine the continuance of the manifestations of force; the non-nitrogenous serve to produce heat. The former are the builders of organs and organised structures, and the producers of force; the latter support the respiratory process; they are *materials for respiration.*

The necessity for the simultaneous presence of both, of the plastic and respiratory materials, and for their due admixture, is now obvious. The sum of both, daily required by the body, depends on the amount of oxygen taken up; their relative proportion depends on the causes of loss of heat and expenditure of force.

With an equal expenditure of force in work, a man requires, in summer, a less supply of respiratory food than in winter—in the south less than in the north; and if men consume equal weights of these substances in different seasons or climates, they are found in one case—that of a fruit diet—to be richer in oxygen, as are vegetable acids and sugar; in the other—that of the train oil and bacon of the inhabitants of Arctic regions—richer in combustible elements.

Neither the formation of organs from the constituents of the blood, nor their employment in manifestations of force, can be conceived without the presence of non-nitrogenous substances. We find, in eggs, for 10 parts of albumen 15 parts of non-nitrogenous matter (fat, calculated as starch), the greater part of which disappears during incubation. By the combination of the elements of the fat with the oxygen of the air, a certain amount of heat is developed, and the action of the external heat of incubation assisted. Carbonic acid and water are formed, and, by the latter, the water lost by evaporation is in part replaced. Lastly, by the presence of the fat, the influence of the oxygen is kept in equilibrium, and reduced to the due measure of what is necessary for the formation of the tissues. But an animal which respires consumes a much larger amount of oxygen than is used for similar purposes in the egg during incubation, and consequently the amount of respiratory matter in its food must be in proportion to the increased consumption of oxygen. We may, perhaps, conclude from this, that the proportion of non-nitrogenous to plastic matter in eggs, is the minimum required by warm-blooded animals in their food; the smallest proportion consistent with life under any circumstances.

Milk-sugar and grape-sugar (which latter is formed from starch and cane-sugar in the digestive process), disappear in the blood with extreme rapidity, so that it has only in very few cases been possible to detect them in the blood. In like manner the fat consumed by a man or beast, whose weight does not change from day to day, entirely disappears.

If more fat be added to the food of animals than corresponds to the inhaled oxygen, the excess is stored in cells, the walls of which consist of the same substance which forms the chief part of membranes and of bones. If the constituents of the blood or of the food do not suffice for the formation of these cells, the substance of the muscles is employed for that purpose; the animal gains in fat, and loses in muscular flesh. Beyond this point, again—as happens in geese when fattened in a certain way—the fat accumulates in the blood, causing disease, and finally death. (Persoz in the Ann. de Chim. et de Phys.: Nouv. Série, XIV., 417.)

If animals receive in their food a larger amount both of plastic and of respiratory matter (not fat) than is required for the support of their vital and respiratory processes, the plastic matters accumulate in the form of flesh and cellular tissue; while the others (sugar, milk-sugar, &c.) are converted into fat.

This important fact; namely, that the sugar formed in digestion from the starch of grain, potatoes, and leguminous seeds, is converted into fat when sufficient materials are supplied for the formation of cells, has been placed beyond a doubt by the experiments of Persoz and Boussingault. (See the Memoir last referred to, p. 419.)

It has already been pointed out, that grape-sugar and milk-sugar have a composition analogous to carbonic acid. For one equivalent of carbon, carbonic acid contains two equivalents of oxygen; grape-sugar and milk-sugar, for one equivalent of carbon, also contain two equivalents—namely, one equivalent of oxygen, and, in place of the second equivalent of oxygen, one equivalent of hydrogen. The conversion of sugar into carbonic acid ultimately consists, therefore, in a formation of water, or at least depends on that formation. The oxygen absorbed in respiration combines with the hydrogen of the sugar to form water, and when the hydrogen has been replaced by its equivalent of oxygen, the sugar at once passes back into carbonic acid. On this view, no true combustion of carbon occurs in the living body; but the carbonic acid is formed by a process of substitution, in this case—one of decay, or slow oxidation, from a body rich in hydrogen, the hydrogen of which is oxidised and removed, and replaced by one or more equivalents of oxygen.

The proximate condition of the formation of fat, or of the deposition of the combustible respiratory materials in the cellular tissue of the body, is *a deficiency of oxygen.* Were the supply of oxygen sufficient to convert the carbon and hydrogen of these substances into carbonic acid and water, these elements would be expelled, and no part of them would be accumulated in the body in the form of fat.

A knowledge of the phenomena of fermentation, allows us to penetrate into the processes by which, in the animal body, the highly oxidised sugar is converted into fat, a body containing so little oxygen.

Fermentation, in its results, is always a resolution or splitting up of a complex atom into two, one of which contains most of the oxygen, the other, very little. In the alcoholic fermentation of sugar, while two-thirds of the oxygen are separated as carbonic acid, we obtain the easily inflammable and combustible alcohol, much less rich in oxygen. From the same sugar, by the separation of two oxidised products, carbonic acid and a certain amount of water, we obtain the oil of potato spirit, (Fusel oil, oil of grain) which approaches still more closely to fat oils in its physical characters; and when the separation of carbonic acid is accompanied by that of a certain amount of hydrogen, we obtain butyric acid, a true oily acid.

The origin of fat in the animal organism, presupposes precisely similar conditions; we regard the formation of fat as the result of two processes, which occur simultaneously. One is an imperfect process of oxidation (of decay or eremacausis), by which a certain amount of hydrogen is separated from the elements of sugar; the other, a process of splitting up a complex atom (of fermentation), by which a certain amount of oxygen is separated from the elements of sugar, in the form of carbonic acid. (See Animal Chemistry.)

The opinion that this transformation is determined by a ferment in the liver, which behaves towards sugar, in the production of fat, as saliva does towards starch, or as the lining membrane of the stomach does in digestion, and that hence the liver is the seat of this process, is not destitute of probability, but requires to be more accurately demonstrated.*

All substances which serve as food to men and animals contain always and under all circumstances a certain amount of fatty matter, or of bodies analogous to fats in their characters. The flesh of wild animals, however, is usually devoid of fat.

In all those cases in which the weight of the body and the quantity of fat remain unaltered, we may therefore conclude, that fat, sugar, and starch, are exclusively employed in supporting respiration, and that the latter are not employed to produce fat. The formation of fat, beyond the limit of the quantity required by the body for the promotion of the organising processes, or the deposition of fat in the fattening of animals, is always the result of a misproportion between the respiratory and nutritive processes, and

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* When a fresh calf's liver is cut in pieces, covered with water, and exposed to a temperature of from 98·6° to 104° F., a remarkable fermentation begins after four or five hours. The liver becomes covered with a number of gas-bubbles, chiefly formed of hydrogen. Each bubble, as it rises, may be kindled at the surface. In an open vessel, during the first hours of this fermentation, no putrid smell is observed. It is hence obvious, that the liver contains a substance which, in a certain state of decomposition, becomes a ferment powerful enough to decompose water, the oxygen of which is taken up by the elements of the ferment.

rather a sign of a morbid than of a normal healthy state. Nature has destined the non-nitrogenous bodies for the support of the animal heat, and we find all food most wisely compounded for this object. Nature has given to the organism the power to reduce every disturbance of the vital functions to a minimum of hurtful effect by storing up the excess of combustible elements. These elements, in the form of fat, being separated from the blood, and deposited externally to the circulatory system, in a form well adapted to future use, the blood maintains its normal composition. By the separation of the combustible elements from the blood, a deficiency in that fluid of the oxygen indispensably necessary for other purposes is prevented, and the equilibrium preserved.

The fact, that the plastic substances also, in certain processes of decomposition, as in putrefaction, are resolved almost entirely into ammonia and oily acids (butyric and valerianic acids) renders conceivable the opinion, that these substances may serve, under certain circumstances, for the production of fat in the animal organism. It appears at all events significant in regard to the formation of fat in the living body, that the production of fatty or oily acids, such as butyric acid, from non-nitrogenous matter, out of the body, is only effected by ferments, the elements of which are themselves in the condition of butyric fermentation; and it is not altogether improbable, that in the living body also, a similar relation exists between plastic and non-nitrogenous bodies, in reference to the formation of fat.

Equal weights of the different respiratory materials contain very unequal quantities of combustible elements; as may be seen by the following table:—

	Grape Sugar.	Cane Sugar.	Starch.	Alcohol.
Carbon . . .	40·00	42·10	44·44	52·18
Hydrogen . .	6·66	6·43	6·17	13·04
Oxygen . . .	53·34	51·47	49·39	34·78
	100·00	100·00	100·00	100·00

The amount of carbon and hydrogen in fatty bodies is much greater. Olive oil, for example, contains 77 per cent., hog's lard and mutton suet 79 per cent. of carbon, and 11 or 12 per cent. of hydrogen. All other fats have a composition intermediate between these two.

Now, since the power of these substances to develope heat by their combination with oxygen, depends on the proportion of combustible elements, contained in equal weights, and since the amount of the oxygen required for their complete combustion, rises with that of the carbon and hydrogen; it is easy to calculate, approximatively, their relative values as producers of heat or supporters of respiration. The following table contains the different respiratory materials, arranged in a series; the numbers express how much of each is required to convert a given weight of oxygen into carbonic acid and water; or, approximately, how much of each must be taken in the food, in order, with the same consumption of oxygen, to keep the body at the same temperature during equal times.

100	Fat.
240	Starch.
249	Cane-sugar.
263	Grape-sugar (dry), Milk-sugar (cryst.).
266	Spirits, of 50 per cent. of Alcohol.
770	Fresh lean flesh.

Hence it appears, that 1 lb. of fat performs the same amount of work, in respect to the respiratory process, as $2\frac{2}{5}$ lbs. of starch, or $2\frac{1}{2}$ lbs. of cane-sugar, or $7\frac{7}{10}$ lbs. of muscular flesh.

Fat is the best, muscular fibre appears the worst of all respiratory materials. In calculating the respiratory value of muscle, it has been assumed, that the flesh consumed as food is ultimately transformed into urea, carbonic acid, and water. This supposition is only true in part; for, in the urine and the intestinal secretions, other compounds of nitrogen are excreted, which contain a much larger proportion of carbon than urea. At all events, that portion of carbon which is separated in the form of compounds of nitrogen takes but a very insignificant share in the production of the heat of the body.

The plastic matters in the food contain nitrogen and carbon in the proportion of 1 equivalent to 8. If no other nitrogenous body than urea were contained in the urine, urine would be found to yield, for 1 equivalent of nitrogen, only 1 equivalent of carbon. But, in his experiments on the nutritive process in the horse and cow, Boussingault found, in the urine of the horse, nitrogen and carbon in the proportion of 1 equivalent to 6·6 equivalents; and in that of the cow, 1 equivalent to 16. (Ann. de Chim. et de Phys. LXXI. 122.) In special experiments made on this point in my laboratory, there were found in the urine of the horse, for 1 equivalent of nitrogen, 5 equivalents; in that of the cow, 8 equivalents; in human urine, 1·8 equivalents of carbon. The excreta of a pig, liquid and solid taken together, the food having been potatoes, contained nitrogen and carbon in the proportion of 1 to 10 equivalents. These facts might, perhaps, justify the conclusion that the combustible elements of the plastic matters in the food, in many animals, are either not sent out from the body through the skin and lungs at all, or are so only to a very small extent, and that we can hardly assign to them any share in the production of the animal heat.

LETTER XXVIII.

In the two preceding letters there has been ascribed to certain constituents of seeds, roots, tubers, herbs, fruits, and flesh, the power of supporting the processes of nutrition and respiration; and it will appear as a very striking contradiction, when it is stated that no one of these substances, by itself, neither caseine alone, nor the substance of muscular fibre, the albumen of eggs or of the blood, nor the corresponding vegetable products, are able to support the plastic or formative processes; that neither starch, sugar, nor fat can sustain the process of respiration. Nay, it may excite still greater astonishment, to add, that these substances, even when mixed, no matter in what proportions, are destitute of the property of digestibility, without the presence of certain other substances; so much so, indeed, that if these other conditions be excluded, the above named compounds are utterly unable to effect the continuance of life and of the vital phenomena.

In the numerous experiments of physiologists and chemists, in which the attempt was made to feed animals with these substances, alone or mixed together, all the animals died, after a shorter or longer time, with the appearances which accompany *starvation*. Even after a few days, the utmost tortures of hunger were found insufficient to induce these animals to take the food offered to them; since the experience of these few days, and their instinct, at first deceived, told them that the introduction of this food into their stomachs was as truly indifferent or useless, for the purposes of nutrition, as the eating of stones.

On the other hand it is a fact, confirmed by the experience of thousands of years, that flesh and bread, either separately or mixed together, as well as the milk of animals, suffice to support life in full vigour, without the necessity of adding any other substance whatever. And hence it follows, necessarily, that these articles of food,—flesh, bread, and milk,—and likewise the plants, or parts of plants, consumed by the herbivorous animal, must contain, and in the due proportion, those other conditions, the presence and co-operation of which is indispensably necessary for the processes of digestion and nutrition.

These necessary matters, essential to the organic processes, by the presence of which the plastic constituents of food and the respiratory materials acquire those properties which render them fit and proper for the support of life, are *the incombustible constituents, or the salts of the blood*.

The incombustible parts of the blood of all animals are of the same nature and quality. Leaving out of view such as are accidental or variable, the blood, at all times and under all circumstances, contains certain quantities of *Phosphoric Acid*, *of Alkalies* (*potash and soda*), *Alkaline Earths* (*lime, magnesia*), *Iron* (*oxidised*), and *Common Salt* (*chloride of sodium*).

All these matters, before they became parts of the blood, were constituents of the food of man or of the fodder of animals. If, then, it be true, that these substances take or have taken a necessary and determining part in converting the constituents of food into constituents of the body, it follows, that no kind of food can sustain life, in which these substances are wanting; that all kinds of food for man or animals, which possess full nutritive power, must contain these bodies in the proportions adapted to the formation of blood; and that we can deprive the food of its sanguific properties, if we deprive it of these conditions, indispensable to those peculiar properties.

Analytical chemistry has furnished the strictest proofs of the justice of these conclusions, by showing, that turnips, potatoes, and the herbs eaten by the herbivora, contain the same incombustible constituents as their blood, and very nearly in the same proportion.* The constituents of the ash of the blood of graminivorous animals are identical with those of the ash of grain ; the incombustible constituents of the blood of men and of such animals as consume a mixed food, are the constituents of the ashes of bread, flesh, and vegetables. The carnivorous animal contains, in its blood, the constituents of the ash of flesh.†

The blood of all animals has invariably an alkaline character, arising from the presence of a free, fixed alkali.

All articles of food which alone, as bread and flesh, or when mixed with vegetables, are capable of sustaining the process of sanguification and nutrition, contain

Ashes of	Sheep's blood. Dr. Verdeil.	Ox blood. Dr. Stolzel.	White cabbage. Stammer.	White turnips. Stammer.	Potatoes. Dr. Griepenkerl.
* Phosphoric acid	14·80	14·043	13·7	14·18	16·83
Alkalies . . .	55·79	59·97	49·45	52·00	55·44
Alkaline earths	4·87	3·64	14·08	13·58	6·74
Carbonic acid .	19·47	18.85	12.42	8·03	12.00

The ashes are calculated in 100 parts, after deducting the common salt and iron, the loss or deficiency in 100 parts consists of accidental constituents, as sulphuric acid, silica, &c.

Cheese made with rennet, in this case Gruyère, contains, according to the analysis of Johnston, for 45 parts of phosphoric acid only 13·48 of alkalies, and 41 of lime and magnesia.

Ashes of	Dog's blood. Dr. Verdeil.*	Ox flesh. Dr. Stolzel.†	Pig's blood. Dr. Strecker.
† Phosphoric acid . .	36·82	42·03	36·5
Alkalies	55·24	43·95	49·8
Alkaline earths . . .	2·07	6·17	3·8
Silicic acid, and Sulphuric acid	5·87	7·85	9.9

Ashes of	Peas. Will and Fresenius.	Fowl's blood. Dr. Henneberg.	Rye. Will and Fresenius.
Phosphoric acid . . .	34·01	47·26	47·29
Alkalies	45·52	48·41	37·21
Alkaline earths . . .	9·61	2·22	11·60
Silicic acid, and Sulphuric acid	10·86	2·11	3·90

* Fed with flesh. † Fed with peas and potatoes.

carbonic acid or phosphoric acid, and alkalies, the two latter in such proportion that, if we suppose them dissolved, the alkalies invariably predominate.

That this free alkali plays an indispensable part in the process of sanguification and in the functions of the blood, is plainly seen in the before-mentioned experiments of the French academicians; for the dogs, which, when fed on animal fibrine, on caseine, or on flesh boiled and pressed out, died of starvation, received, in these forms of food, a quantity of alkalies altogether insufficient for sanguification. Flesh, from which the fluids have been pressed out, contains phosphoric acid and alkalies in such a proportion, that if we suppose them dissolved, the acid and not the alkali predominates. If both could become at the same time constituents of the blood, the blood would have an acid and not an alkaline re-action.

But, on a closer examination, an acid state of the blood appears to be utterly irreconcileable with the functions which it has to perform in the nutritive and respiratory processes. The free alkali gives to the blood a number of very remarkable properties. By its means the chief constituents of the blood are kept in their fluid state; the extreme facility with which the blood moves through the minutest vessels, is due to the small degree of permeability of the walls of these vessels for the alkaline fluid. The free alkali acts as a resistance to many causes, which, in the absence of the alkali, would coagulate the albumen. The more alkali the blood contains, the higher is the temperature at which its albumen coagulates; and with a certain amount of alkali, the blood is no longer coagulated by heat at all. On the alkali depends a remarkable property of the blood,—that of dissolving the oxides of iron, which are ingredients of the colouring matter of the blood, as well as other metallic oxides, so as to form perfectly transparent solutions.

The free alkali plays a peculiarly important part in the processes of respiration and secretion, which we shall explain more minutely in considering the urine.

The significance and importance of phosphoric acid in the vital process is obvious, when we remember that this acid is a never-failing ingredient of all the organised structures of the animal body. The substance of muscular fibre, the fibrine of blood, the pulmonary tissues, the liver and the kidneys contain a certain amount of phosphoric acid in chemical combination. The ashes or incombustible ingredients of the fluids of the flesh are, in all animals, of the same nature and quality. They consist of alkaline phosphates, phosphate of potash, and phosphate of magnesia. The bones of the vertebrata contain more than half their weight of the phosphates of lime and magnesia. The substance of the brain and the nerves contain a phosphoric acid, coupled with a fat or with a fatty acid, the phosphoric acid being, partly, in combination with an alkali.[*]

The phosphoric acid contained in these tissues is derived from the blood. The blood contains, under all circumstances, a certain amount of phosphoric acid.

In the present state of science, it is not yet possible to express a decided opinion as to the mode of action of the phosphoric acid in the organic process, and we must for the present be satisfied with deducing, from its constant presence in all the juices and organised tissues of the body, the conclusion that it is indispensable for the vital operations.[†]

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Ashes of	Free Phosphoric Acid.	Alkaline Phosphates.	Earthy Phosphates.
Horse flesh (Dr. Weber) .	2·62	80·96	16·42
Ox flesh, washed out, (Dr. Keller)	17·23	48·06	26·26
Ox brain (Dr. Breed) . .	16·57	74·41	9·02
Yolk of Egg (Dr. Polek) .	36·74	27·25	34·70

The phosphates are calculated according to the formula $P O_5, 2 M O$. The horse flesh was from the fore-leg of a lean horse, entirely freed from blood by washing out the brachial artery by injection.

[†] Some facts seem to favour the opinion, that the phosphoric

If we imagine the animal organism to be divided into two parts, observation shows that the changes going on in these are effected in one by the co-operation of a predominant alkali, in the other by that of a free acid.

All organised solid parts contain alkaline bases and phosphoric acid, in such a proportion that if we suppose them combined, the phosphoric acid predominates. (See note, p. 386.)

The blood contains an excess of fixed alkali; but

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acid, and the acid earthy phosphates can form true chemical compounds with albumen, and with the substance of the membranes; and that many peculiarities of the latter, as, for example, their insolubility in water and in alkaline fluids, depend on this cause. If, for example, we add to milk, cautiously, a diluted acid, till the alkaline re-action disappears, and then heat it to boiling, it now coagulates like white of egg. The caseine, thus precipitated, differs very essentially from pure caseine, by its insolubility in alkaline fluids. The caseine coagulated from milk by rennet has the same characters. Both are compounds of caseine with the phosphates of the alkaline earths (lime and magnesia); or if we consider the so-called pure caseine as a complex acid containing phosphoric acid, the insoluble caseine is the lime or magnesia salt of this acid. The phosphate of lime existing in common gelatine in chemical combination has a most decided share in giving to that substance the property of forming a jelly. It is well known, that by continued boiling of animal skins and bones there is obtained a solution of glue, which, on cooling, forms a stiff jelly. But if the solution of this jelly, alone, or with the addition of alkali, be boiled for a still longer time, it loses the property of gelatinising, and at the same time phosphate of lime is separated.

The very peculiar behaviour of the fibrine of blood in contact with hydrochloric acid has been pointed out at p. 256. When the fibrine, which in the dilute acid liquid has swelled up to a jelly, is heated to boiling with the liquid, it dissolves, forming a solution that may be filtered, in which phosphoric acid and lime may now be detected by re-agents; and by the separation of these two bodies from the organic ingredient, the fibrine of blood, exactly like gelatine, becomes soluble in cold water. It is probable, that the coagulation of albumen, of the serum of blood, and of eggs depends on the separation of alkali, and the formation of a new compound of albumen with phosphoric acid and lime, insoluble in the cold, in water, dilute acids, and alkalies.

the lymph and chyle also have an alkaline re-action; and it would appear to follow, from this, that on the alkali depend, not only certain properties, but also the formation and production of the blood.

The formation and production of the organised structures cannot be imagined without an excess of phosphoric acid.

A similar contrast is observed in the egg. The white of the hen's egg contains, among its incombustible constituents, an excess of alkali; the yolk contains free phosphoric acid. (See note, p. 386.)

When we compare the ashes of the blood of herbivorous, graminivorous, and carnivorous animals together, we observe, in the proportion of the alkalis to the phosphoric acid, most extraordinary differences.

The blood of the pig and of the dog contains 36 per cent, that of fowl above 40 per cent, that of oxen and sheep not more than from 14 to 16 per cent of phosphoric acid. (See note, p. 384.)

How, it may be asked, are such marked differences to be reconciled with the constant functions of the blood? If the incombustible ingredients of ox blood, in the proportions therein found, be necessary for the vital changes in the body of the ox, how can we explain the fact, that the blood of the pig or dog, with a composition so different, can serve the same purposes; which purposes we see attained in them exactly in the same way as in the body of the animals fed on grass? In fact, analysis can discover no difference in the composition of the organs or of those parts of the body external to the blood vessels, as far as concerns these incombustible constituents. While the ingredients of the ashes *of the blood* of herbivorous and carnivorous animals differ to such an extent, that we can at once distinguish them by analysis, merely by observing the amount of phosphoric acid in each, it is utterly impossible, by analysing the incombustible ingredients *of the flesh*, to distinguish that of the ox from that of the pig or dog, or to say, which ashes have been obtained from the flesh of the carnivorous or of the herbivorous animal. The ashes of the juice of flesh of the ox, calf, sheep, pig, dog, marten, fox, and fishes, always contain phosphoric acid and alkalies in the same proportion as the pyrophosphates (bibasic phosphates). Those parts of the muscular substance, of the cellular tissue, of membranes, of the pulmonary and hepatic tissues, which are insoluble in cold water, always contain an excess of phosphoric acid, so that, in their incineration, certain quantities of metaphosphates (monobasic phosphates) are always formed.

But if the constituent parts of the organs and of all the tissues of the herbivora are, in regard to their incombustible elements, of the same composition as those of the carnivora ; if the variation or increase of the amount of phosphoric acid in the blood does not alter nor increase the amount of this acid in the fluids of the muscular system and in the tissues, and its diminution in the blood does not diminish its amount in those other parts, it follows, of course, that the increase of phosphoric acid in the blood has no influence whatever on the process of formation of the blood itself.

The blood carries to all parts of the body the necessary phosphoric acid, and must therefore always contain a certain amount of that acid ; but the phosphoric acid plays no part in sanguification or in the functions of the blood, because its properties as an acid entirely disappear in the excess of alkali in the blood.

In the blood of animals belonging to different classes in respect to their food, we observe a variation in two ingredients, namely, phosphoric acid and carbonic acid ; but this difference in composition is without any influence on the properties of the blood, which retains its alkaline character. In the blood of the herbivora we find the alkali in part combined with carbonic acid ; in that of the carnivora we find this carbonic acid represented and replaced by phosphoric acid, without any alteration of the character or of the functions of the blood.*

This is again one of the numberless facts, which fill with inexpressible admiration the soul of the observer of natural arrangements; namely, that an alkaline phosphate is identical in its properties with an alkaline carbonate. Contrary to all known laws, it appears to the chemist like a miracle, that two acids, a gaseous one and a fixed one, one of the weakest and one of the strongest, which of all acids differ most in composition, can form, with the alkalies found in the blood, compounds of the same chemical character. Phosphate of soda has an alkaline taste and reaction, like the carbonate; and its solution in presence of free carbonic acid takes up as much of that acid as the carbonate of soda does, and like it, only more easily, gives it off by agitation with air, in vacuo, or by evaporation, without losing its power of again absorbing the carbonic acid.

It is easy from this to understand, that if certain functions belong to the blood, which depend on its chemical character, on its alkaline quality,—that, for these objects, a change of the acid combined with the alkali, the replacement of the carbonic acid of the carbonated alkali by phosphoric acid, and *vice versâ*, has no influence, because it causes no alteration of the essential properties of the blood.

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* Ashes of . . .	Human blood,	Calves' blood,	Sheep's blood.
Phosphoric acid	31·787	20·145	14·806
Alkalies and Alkaline earths	58·993	66·578	60·576
Carbonic acid	3·783	9·848	19·474

These analyses, by Dr. Verdeil, show, that as the amount of phosphoric acid diminishes, that of carbonic acid increases. The difference in the quantity of alkalies is, in part, only apparent, for they consist of potash and soda, of which we know that they replace each other in very unequal weights. Common salt and iron have been deducted. What is wanting of 100 parts is accidental ingredients.

The blood is the common soil, from which all parts of the living body are developed in all animals in the same way, and with the same unchangeable composition; but it is at the same time the source of animal heat, and its canals are the passages through which the matters unfit for the vital changes, and the worn out parts (the products of the change of matter) are carried to the organs of secretion and thus expelled from the body.

For these purposes, the blood must possess all the necessary conditions. In the combustible ingredients it has the matters which are to become the organs of vital activity, or are to serve for the production of heat; and in the incombustible constituents it has the indispensable conditions of its efficiency in these respects. In the formative process we see the phosphoric acid (and besides it no other fixed or incombustible acid) perform a defined part. The processes of sanguification, of the production of heat and of secretion, are carried on under the influence of a predominating alkali.

The partial replacement of phosphoric acid by carbonic acid, and *vice versâ*, which may take place in the blood, without alteration of its properties, explains how it happens that the change from vegetable to animal diet, causes no change appreciable in ordinary circumstances in the body of man, although, by that change of diet, an essential difference in the composition of his blood as regards the incombustible constituents is produced.

We can now with the greatest ease and certainty determine beforehand, from the known composition of the ashes of the food, the nature and quality of the incombustible constituents of the blood; since we know that those of the blood are derived from the food, and that both are identical.

When the food consists of bread or flesh, which leave in their ashes no carbonates, but only phos.

phates, the blood contains only phosphates; if we add to the bread or flesh, potatoes or green vegetables, the blood acquires a certain amount of alkaline carbonates; if we replace the bread and flesh entirely by fruits, roots, or green vegetables, the blood of man acquires the composition and quality of that of the ox or sheep.

But although the exchange of phosphoric and carbonic acids in the blood, when the diet is changed from animal to vegetable, appears to have no influence on the processes of sanguification, nutrition and production of heat, yet the process of secretion is very essentially modified in its form by this exchange.

It is evident, that in the normal state of health, in which the weight of the body of man or animals does not change, the alkalies, alkaline earths, phosphoric acid, and oxide of iron, received in the food, do not accumulate in the body, but are daily expelled in the same proportion as they are introduced in the food.

We know with perfect certainty, that this excretion is effected by two organs of secretion, namely, the kidneys, and the intestinal canal.

The constituents of the ashes of the urine and of the solid excreta are, in the normal state, equal in weight to the incombustible ingredients in the food; it is only when the individual increases in organised parts, that is, in weight, that certain quantities of phosphates are retained in the new parts as belonging to their composition.

A knowledge of the incombustible constituents of the food of healthy men, or of the fodder of animals, enables us to conclude with mathematical certainty, from the nature of the food, as to that of the urine and solid excreta, and to predict what must be the reaction of the urine, and in what proportion these constituents are to be found in the urine and fæces.

The incombustible constituents of bread, flesh, seeds, roots, tubers, herbs and fruits, are, in all these articles of food, of the same nature and quality, but in very different proportions. They may be easily distinguished from one another by their properties.

The alkalies (potash, soda,) are, both alone, and in combination with phosphoric, sulphuric, and carbonic acids, easily soluble in water.

The alkaline earths (lime, magnesia,) are in their neutral compounds with phosphoric and carbonic acids, insoluble in water.

The *carbonates* of the alkaline earths, on the other hand, dissolve in water containing *free carbonic acid;* the *earthy phosphates* in water containing *free phosphoric acid*, or any free numeral or organic acid.

The substances above-named are the never-failing constituents of the ashes of the food of man, or of the fodder of animals. *Phosphoric acid*, the *alkalies*, and the *alkaline earths* (with *peroxide of iron*, and, in fodder, *silicic acid*,) are present, as such, before combustion. *Sulphuric* and *carbonic acids* are products of the combustion of sulphur and carbon. If we suppose these ashes to be acted on by water, they are divided into two parts. The soluble matters are taken up by the water; the insoluble are left in the residue.

If the ash contain phosphoric acid and sulphuric acid (and silicic acid) in such a proportion that, taken together, they suffice to neutralise the alkalies and alkaline earths which are present, we obtain

In Solution.		In the Residue (undissolved).	
Phosphoric acid	Potash,	Phosphoric acid,	Lime,
Sulphuric acid	Soda.	Silicic acid.	Magnesia,
			Peroxide of iron.

If the quantity of alkaline earths present be sufficient to combine with all the phosphoric acid in the ash; if, therefore, there be a want of phosphoric acid o combine with the alkalies, all the phosphoric acid s found in the insoluble residue, and we obtain

In Solution.		In the Residue.	
Carbonic acid, Sulphuric acid.	Potash, Soda.	Phosphoric acid, Carbonic acid, Silicic acid.	Lime, Magnesia, Peroxide of iron.

In the living body the food undergoes precisely the same change, as if we had burnt it in a furnace, and in regard to the incombustible constituents a perfectly similar division takes place.

In the process of digestion those constituents of food or of fodder, whether combustible or incombustible, which are soluble in alkaline or slightly acid liquids, are dissolved, and taken into the circulation. By the action of the oxygen absorbed in respiration, the combustible portions are ultimately burnt—that is, oxidised. The non-nitrogenous bodies are converted nto *carbonic acid* and *water*, the plastic substances into *uric acid*, *hippuric acid*, and *urea*, their sulphur into *sulphuric acid*.

By means of the organs of secretion, the kidneys and the intestinal canal, the above named products of the organic process of combustion and the constituents of the ashes of the food, in so far as they are unfit for further use in the vital operations, are expelled from the organism. The urine contains the soluble, the fæces the insoluble constituents, of the ashes of the food.

The alkalies, as well as the products of the change of matter, which form with them soluble compounds, are contained in the urine; the rest are found in the fæces.

When the food has been bread or flesh, the ashes of which contain only phosphates, the urine contains the alkalies in the form of alkaline phosphates.

If the food has consisted of roots, green vegetables, and fruits, the ashes of which contain, as soluble salts, only alkaline carbonates, the urine contains alkaline carbonates.

The products of the organic process of combustion, formed in the body—sulphuric acid, uric acid, hippuric acid—have a powerful attraction for the alkalies. When these acids are added to a solution of phosphate of soda ($P\,O_5$, 2 M O, H O), or of carbonate of soda, they share the alkali with the phosphoric or carbonic acid; by removing from the salts of these acids a part of the base, they set free a certain amount of phosphoric or of carbonic acid.

The very same thing happens in the separation of the urine from the blood. The alkalies hold in chemical combination all the acids present in the blood, or formed in that fluid.

The urine of man and animals always contains a free acid, or an acid salt.

During the separation of the urine from the blood, in consequence of the addition of sulphuric, hippuric, or uric acid, to the alkaline phosphate, a part of the alkali is removed from that salt, a corresponding portion of its phosphoric acid is set free, the salt, originally of an alkaline reaction, becomes neutral or acquires an acid reaction. If the soluble parts of the ash of the fodder consisted of alkaline carbonates, these pass out of the body in the urine in the form of bicarbonates, combining with the free carbonic acid of the blood.

But since a liquid, which is rendered acid by free phosphoric acid or by a fixed acid, has the property of dissolving the phosphates of lime and magnesia, and a liquid rendered acid by free carbonic acid has a similar power of dissolving the carbonates of lime and magnesia, the urine which is acid from phosphoric acid always contains earthy phosphates; while that which is acid from carbonic acid always contains earthy carbonates in solution.

With food consisting of Flesh, Bread, Peas, Beans, or Lentils, the Urine contains:—	With Vegetable food, Hay, Clover, Turnips, Potatoes, fruit, &c., the Urine contains:—
Free Phosphoric acid.	Free Carbonic acid.
Phosphates of { Lime, Magnesia.	Carbonates of { Lime, Magnesia.
Phosphates, Sulphates, Urates, Hippurates, } of the Alkalies.	Carbonates, Hippurates, Sulphates, } of the Alkalies.
This urine has a permanent *acid* re-action. Acid urine contains (usually) uric acid.	This urine has a transient acid re-action; a permanent *alkaline* reaction. Alkaline urine contains no *phosphoric acid*, and no *uric acid.*

From these researches it clearly appears, that the acid, alkaline, or neutral state of the urine of healthy men or animals, as well as the presence in the urine of phosphoric and uric acids, of earthy phosphates or earthy carbonates, ultimately depends on the nature and quality of the constituents of the ashes of the food or fodder.

The urine of a pig fed on potatoes, which is alkaline, becomes acid as soon as the animal receives corn or peas in its fodder. In like manner, the urine of man loses its usual acid reaction, and becomes neutral or alkaline, when juicy fruits, cherries, apples, potatoes, roots, and green vegetables, are added to his food in a certain proportion.

The salts of the urine are separated from the blood by the kidneys; before this separation they formed part of the blood.

The analysis of the urine enables us to compare its incombustible constituents with those of the blood; and observation shows, that in regard to the proportion of soluble salts with alkaline base, there is hardly any difference between them.* If we incinerate the

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* Analysis of human urine, after deducting the common salt:

	Phosphoric Acid.	Alkalies.	Alkaline Earths.	Sulphuric Acid, Silicic Acid.
Urine (Porter), Giessen	34·24	47·76 *	7·62	12·38
Urine (Fleitmann) Berlin	34·03	48·03	9·02	8·92

* Here 4·06 parts of soda have been reduced to potash and calculated in that form.

blood of a healthy person, and also his urine, and lixiviate the ashes with water, the soluble salts of the blood ash are in nature the same as those of the urine; and it is extremely probable, that, in regard to their relative proportions also, a constant relation prevails.

We have, therefore, every reason to hope, that we may be enabled, by a very simple chemical operation, to reason backwards from the urine to definite conclusions as to the quality and composition of the blood; and it will require only a small number of comparative examinations of the urine and of ashes of the blood in different diseases, to enrich pathology with a means of research invaluable from the certainty of its indications; by the aid of which the physician may ascertain the changes occurring in the composition of the blood in disease, and may judge of their influence on the functions of the blood, and consequently on the most important vital processes.

It does not require much chemical knowledge to perceive that the discovery of the law which regulates the dependence of the quality and functions of the blood on the nature and amount of its incombustible constituents, is the foundation-stone of medicine and physiology; and that it is utterly absurd even to dream of a rational science of medicine, before we have laid this foundation-stone, on which must rest the solution of all questions concerning the animal economy. It is impossible for the chemist not to acknowledge, that the alkaline quality of the blood is one of the first and most important conditions of the organic process of combustion, of the production of animal heat, and of the change of matter in the body.

A number of organic compounds acquire, by contact with, or in presence of a free alkali, the power of combining with oxygen (of burning), which, alone, they do not at all possess at the ordinary temperature of the air, or at the temperature of the body. (Chevreul.) The influence of alkalies in this way is most strikingly seen in such substances as are coloured, and become decolourised under these circumstances, or in such as are colourless, and become coloured, as they are destroyed. Carmine, the most durable organic colouring matter known to us, the colouring matters of Logwood and Brazil wood, and *the colouring matter of the blood,* dissolve in solution of potash, and may be preserved for months unchanged. But as soon as air or oxygen is admitted to these solutions, oxygen is rapidly absorbed, and these colouring matters are destroyed. (Chevreul.)

The colourless solution of pyrogallic acid, or that of gallic acid, when mixed with excess of alkali, become, when oxygen is admitted (see p. 331), dark red, and are destroyed in a few minutes. Even alcohol is oxidised, when it contains free alkali, and is exposed to air at the ordinary temperature, and becomes brown.

Milk-sugar and grape-sugar, in presence of a free alkali, and with the aid of a gentle heat, deprive even metallic oxides of their oxygen. (See p. 357.)

The alkalies exert a precisely similar action in the blood; they promote and increase the combustibility of the respiratory matters.

This influence of the alkalies is shown in a decisive manner in the effects produced on the salts of organic acid in the circulation. It has long been observed, that after eating juicy fruits, cherries, strawberries, apples, &c., the urine becomes alkaline. All these fruits, as well as the juices of edible roots, tubers, and green vegetables, contain these alkalies in the form of salts of the organic acids; usually as malates (all kernel fruits, pine apple); citrates (stone fruits, currants, potatoes); tartrates (grapes). It has been shown by Gilbert Blane and by Wöhler, that the pure salts, malates, citrates, tartrates, &c., of the alkalies, when taken internally, behave exactly as the salts in the juices of these fruits and roots. Citrate, tartrate, malate, and acetate of potash, whether given by the mouth, or in enemata, appear in the urine in the form of carbonate of potash.

The acids of these salts, introduced into the blood in the form of neutral or acid salts, are there burned (oxidised) as effectually as in the most perfect apparatus of combustion. The alkaline carbonates which predominate in the urine of herbivorous animals are derived from the same source—namely, from the salts composed of the alkalies with the organic acids contained in the fodder.

In precisely the same way is uric acid destroyed or burnt in the organism in presence of free alkali. In the urine of rabbits, to which had been given proportionally large doses of uric acid, in the form of urate of potash (2 to 2½ grammes, 30 to 40 grains), no uric acid could be detected. It had been converted into oxalic acid and urea, the amount of which last in the urine exceeded the normal quantity at least five-fold. (Frerichs.) But, as is well known, urea corresponds in composition to carbonic acid. It is carbonic acid, in which half of the oxygen is represented and replaced by its equivalent of amide ($N H_2$).

The cause of the so greatly increased combustibility of all these bodies is evidently, as is proved by the most obvious considerations, the alkaline quality of the blood.

The herbivora consume in their fodder a quantity of vegetable acids in the free or uncombined state, which, like the portion combined with alkaline bases, are destroyed and disappear in the circulation (the blood being always alkaline, so that these free acids are also converted into alkaline salts). It can hardly be doubted, that in the organism of the herbivora, exactly as in that of the carnivora, uric acid must be formed, as an imperfect or intermediate product of the combustion of the plastic matters consumed in the change of matter; but in the normal, healthy state, this uric acid never appears in their urine, rich as it is in free alkali.

This fact is satisfactorily explained by the presence of alkaline carbonates in their blood.

The vegetable acids, when they enter the blood, or the uric acid formed in the body, decompose the alkaline carbonates in the blood, and form neutral salts, which are destroyed as fast as they are formed by the oxygen present in the blood, assisted by the free alkali of that fluid. The carbonic acid, thus set free, is given off by the lungs.

The same organic acids, which, in the form of salts, that is, *accompanied by alkaline bases*, disappear so rapidly even in the blood of man, appear in great part unchanged in the urine, when they are taken *without these alkalies*. Even the most combustible of them, such as tartaric and gallic acids, become, in these circumstances, incombustible in the blood of man. Gallic acid, when administered without sufficient alkali, is particularly easy to be recognised in the urine by its property of striking an inky black with the salts of sesqui-oxide of iron.

The cause of this incombustibility is the want of the *free alkali, which determines and promotes the action of the oxygen.*

The blood of man, (and of the dog, with which a large number of these experiments was made,) contains no alkaline carbonate, but only alkaline phosphate.

Now it is certain, that the neutral salts of vegetable acids do not alter the alkaline quality of this blood, while uncombined acids, when they enter the blood, must set free a corresponding amount of phosphoric acid, since they seize a portion of the alkali with which it was combined. This phosphoric acid is not, like the carbonic acid, gaseous and capable of being exhaled by the lungs, but only quits its place in the blood, when compelled by some cause to do so. We must suppose, that that part of the blood which the free vegetable acids reached, totally lost its alkaline character, that it even became transiently acid (a quality which was again removed by the function of the kidneys) and that in consequence of that transient state the vegetable acids, or at least a part of them, lost, in the circulation, their proneness to change and their combustibility. Had the blood, to which free gallic acid was added, continued alkaline, that acid would have been destroyed; for the presence of a free alkali and of oxygen is utterly inconsistent with the continued existence of gallic acid.

The peculiarities of the blood of man and of the carnivora, which are determined by the amount of phosphoric acid, appear in their full significance in the process of secretion. The chemical action of the alkalies meets with a certain resistance from the phosphoric acid combined with them, which resistance does not occur in the blood of the herbivora. The permanent acid re-action of the urine, and the secretion of uric acid, in man and in carnivora, stand in the closest relation to the presence of phosphoric acid in their blood, while the absence of uric acid in the urine of the herbivora is in the same close manner related to the predominant alkaline quality of their blood.

The presence of free carbonic acid in the urine of herbivora is in great part determined by the attraction of alkaline carbonates for carbonic acid. On the other hand, the separation of free acids in the urine of carnivora and graminivora is obviously a condition necessary for the preservation of the alkaline quality of their blood.

If we suppose this separation or excretion of free acids to be checked, even transiently, in consequence of a disturbance in the functions of the kidneys, or, in consequence of a morbidly accelerated change in the tissues (inflammation, fever), the phosphoric acid of these tissues to be set free and to enter the blood, the alteration in the alkaline quality of the blood must at once exhibit itself by increased excretion of uric acid, and by a change in the respiratory process.

These considerations enable us to understand the success, often almost miraculous, which physicians obtain, in many diseases, by a rational diet, by a choice of food made with knowledge of the subject and careful reflection, by mineral waters, and by the vegetable cure or the whey cure.

When we replace the bread and the flesh of ordinary diet by juicy vegetables and fruits, the blood is, beyond all doubt, altered in its chemical character; but this alteration in no way consists in a change of the organic combustible ingredient, for the fibrine and albumen of ox-blood do not in the slightest degree differ in their chemical nature from the fibrine and albumen of the blood of animals fed on flesh or grain, but on a change *in the incombustible constituents*, in a replacement of the phosphoric acid and alkaline phosphates, which exert a disturbing influence in so many diseases (typhoid and inflammatory affections), by alkaline carbonates.

There is probably no fact, which appears to testify so convincingly to the function of the intestinal canal as an organ of secretion, as the absence of iron in the urine generally, and the absence of phosphates in the urine of herbivora.

We can readily understand, that no substance can be contained in urine, which is insoluble in that fluid, and that the phosphates of lime and magnesia are wanting in the urine of the horse and the cow, because a liquid containing so considerable a quantity of alkaline and earthy carbonates has no power of dissolving earthy phosphates.* We find in the urine

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* A solution of carbonate of lime in carbonic acid water, diluted with so much spring-water, that carbonate of potash, or of soda, causes no precipitate, gives, on the addition of the smallest quantity of phosphate of soda, immediately, a permanent turbidity from the formation of phosphate of lime.

of the horse and the cow, no phosphoric acid, although both receive in their fodder, daily, a large amount of phosphoric acid, in the form of soluble alkaline phosphates, which become constituents of their blood. The chemical analysis of the urine * of the same animals whose fæces † and whose fodder ‡ were also analysed, shows us, that the fæces contain all the phosphoric acid of the food in the form of phosphates of lime and magnesia (PO_5, $2MO$), and

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	* Urine (after deducting common Salt).		† Fæces.	
	Horse. (Arzbächer.)	Cow. (Arzbächer.)	Horse. (Buchner.)	Cow. (Buchner.)
Potash . .	28·97	56·74	9·33	17·15
Soda	„	1·31	0·61	6·30
Carbonic Acid .	27·28	31·04	„	„
Lime	27.75	1·74	5·22	7·31
Magnesia . .	4·22	4·09	2·03	4·50
Peroxide of iron .	0·79	0·31	2·03	3·34
Sulphuric acid .	6.48	4·63	3·92	3·23
Silicic acid . .	„	„	59·96	41·00
Phosphoric acid .	„	„	7·92	17.05
	100·00	100·00	100·00	100·00

‡ The horse had daily, on an average, 3½ lbs. of oats, 4 lbs. of rye bread, 10 lbs. of hay, 5 lbs. of straw. The cow had about 52 lbs. of distillery dregs, from potatoes, 12 lbs. of rye straw, 2 lbs. of hay, 1 lb. of pease straw, 1 lb. of oat straw, 1 lb. of barley straw, 12 lbs. of beet root. Of this mixed fodder, Mr. Porter analysed the ashes of the potato dregs, the oats, and the hay.

	Hay.	Oats.	Potato Dregs from Distillery.	Soluble Constituents of the Ash of Dregs.
Potash	20·08	12·94	38·52	54·18
Soda	10·84	2·02	4·47	6·17
Phosphoric acid .	17·35	15·43	16·78	11·99
Lime	8·24	3·00	5·19	„
Magnesia . . .	4·00	7·08	7·33	„
Peroxide of iron .	1·82	0·60	1·50	„
Common salt . .	5·09	„	4·00	5·91
Sulphuric acid . .	2·10	0·49	6·10	8·72
Silicic acid . .	30·00	53·97	2·84	12·12
Carbonic acid . .	0·67	„	12·27	„
	100·00	100·00	100·00	100·00

there can be no doubt that the phosphoric acid set free in consequence of the change of matter, which, from the chemical nature of the urine, could not pass out by the kidneys, must be carried from the blood to the intestines, and that hence a part of the intestinal canal performs the same function as the kidneys, as an organ of excretion. It is difficult, either from the anatomical or chemical point of view, to form a clear notion of this process of excretion, of the existence of which we perceive the most convincing evidence in diseased states (in diarrhæa, for example). But in the study of nature the difficulty of explanation does not destroy the truth of a fact.

Besides the incombustible constituents above mentioned, the blood of man and animals contains a certain amount of common salt and of iron. The quantity of common salt usually amounts to upwards of one half of the total weight of all the incombustible substances in the blood.

The difference of food has no perceptible influence on the amount of common salt in the blood. The blood of a dog, fed for eighteen days on flesh, contained the same proportion of common salt as after twenty days feeding with bread. The common salt in the blood of man, of the sheep, pig, ox, and calf amounts to from 50 to 60 per cent. of the total weight of the ash. The difference in the quantities of salt obtained in different analyses depends in part on the difficulty of avoiding the volatilisation of common salt in the incineration of blood; and the unequal per centage of salt in the blood of different animals depends partly on the varying amount of other constituents, such as phosphoric and carbonic acids.

The great proportion of common salt in the blood is sufficiently remarkable, to be considered with reference to the question of its necessity, as a condition of the vital process.

It is unnecessary particularly to point out, that all the common salt in the blood is derived from the food; but if we compare the ashes of the vegetable food of the cow and horse with the ashes of their blood, we perceive a very striking difference. The amount of that salt in the ashes of the blood is much greater, often tenfold greater than that in the ashes of the fodder. A comparison of the ingredients of the ashes of the urine with those of the ashes of the blood shows, moreover, that the amount of common salt in the ashes of the urine is always less than in those of the blood, and corresponds with that in the ashes of the food. These facts seem to point to the conclusion, that in the circulating system some cause is in operation, which (as the proportion of salt in the blood never goes beyond a certain limit), opposes the increase as well as the diminution of its quantity; that, consequently, the common salt is not merely an accidental, but an essential and constant ingredient of the blood, and that its quantity is fixed within certain limits.

Of the various kinds of vegetable food, seeds contain the smallest amount of common salt; green vegetables and meadow grass (especially *Lolium perenne*) among the plants of the Continent, contain the largest proportion.

It is not easy to determine the full significance and value of salt for the vital process, with the same certainty as we can in the case of phosphoric acid and lime, the indispensability of which for the formative process is an established fact, since they form parts of all the tissues. Salt serves in the organism to assist and promote the most universal changes, without taking a share, by its elements, in the formative process. No organised part or tissue contains chlorine in chemical combination; but there is no fluid of the animal body in which chlorine is absent as a constituent. We discover in animals, which, like those of the Continent, receive in their food only salts of potash, and, except chloride of sodium, no compound of sodium or of chlorine in their food, the elements of the salt, but separated, and in different parts. In the whole muscular system, in the juice of flesh, an abundant quantity of chlorine is found, but combined with potassium, not with sodium ; this chlorine is derived from the common salt. In the secretion of the liver, the bile of land animals, we find a predominating quantity of oxide of sodium, the sodium of which was received in the food as common salt. In the blood of the horse, the cow, and herbivora in general, the quantity of carbonate of soda exceeds that of carbonate of potash two or three-fold, although the ashes of their food hardly contain a trace of carbonate of soda. These relations, from their permanence and fixity, are very trustworthy indications that sodium and soda, from their peculiar properties, are especially adapted for the changes occurring in the blood and blood-vessels, and that potassium or potash, for the same reason, is peculiarly fitted for the changes going on in the muscular system; and that these two alkalies, although so much alike in many other properties, cannot mutually replace each other with reference to all the purposes which they serve. In the blood of man, and of animals fed on grain, the phosphate of potash is always accompanied by common salt ; but we know that these two salts cannot exist together without mutually decomposing each other, yielding phosphate of soda, which in its properties approaches most closely to the carbonate of soda, and chloride of potassium.*

Moreover, when we consider, that the efficient free acid often occurring in digestion, is hydrochloric acid,† which is derived from common salt,—all these facts,

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* When a moderately strong solution of phosphate of potash is mixed with one of common salt, and left to stand in the cold, phosphate of soda soon crystallises out in fine crystals.

† The early observations of Prout and L. Gmelin have lately been confirmed, for many cases, by Dr. Schmidt, of Dorpat.

taken together, seem entitled to be regarded as irrefragable proofs of the necessity of the presence of salt for the vital process, and of the addition of salt to the food of men and the fodder of animals.

The action of free hydrochloric acid on the plastic constituents of food, is very remarkable. The gluten of grain and the fibrine of flesh, for example, dissolve in water which has been hardly acidulated with hydrochloric acid, readily and rapidly at the temperature of the body; and this solubility does not increase, but diminishes, when the proportion of acid in the liquid is increased; so that all the dissolved matter can be again precipitated by moderately strong hydrochloric acid. A solution of common salt has the same effect as the strong acid. The same water, which, by the addition of $\frac{1}{1000}$ of hydrochloric acid, becomes a powerful solvent for the plastic substances, loses its solvent power on the addition of rather more than 3 per cent. of common salt; and all the gluten or fibrine may be precipitated from the acid solution by a solution of salt.

The relations now pointed out between the elements of common salt and the organic processes, are certainly not the only ones which belong to this compound, so remarkable on account of its universal diffusion in nature, and its presence in all organised beings. It is more than probable that it promotes, nay even determines, certain changes and operations, by virtue of its peculiar properties as a salt.

We need only recal the fact, that common salt possesses the property, quite unusual among salts, of forming with urea a chemical compound which crystallises in beautiful large clear rhombic prisms, and which is always found in urine containing common salt.*

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* Among the salts, only some nitrates form similar compounds with urea. The presence of the compound of urea with common salt in the urine of man and animals, is the reason why we often obtain no nitrate of urea from urine, moderately concentrated, and

Even in the vitreous humour of the eye, the urea is accompanied by common salt. By combining with common salt, urea loses certain properties which belong to it as an organic compound; and accurate observations may perhaps show, that the absence of urea, the ultimate product of the organic change of matter, as well as of common salt, in the muscular system, and the passage of urea into the circulation, and its excretion by the kidneys, have a closer relation with the presence of common salt in the blood than is generally supposed.

If, further, we consider, that instinct leads us to add salt to amylaceous food in much larger proportion than to other food; that potatoes, to most men, are hardly eatable without salt; we are involuntarily reminded of the remarkable compound which common salt forms with grape-sugar, the product of the digestion of starch. It is known that diabetic urine generally contains this compound; and the presence of common salt cannot be without some influence on the excretion of sugar by the kidneys.

I cannot here omit to mention, that agriculturists have endeavoured to solve the question as to the necessity or the profit of adding salt to the fodder of live stock, in their own way. The result of the excellent experiments of Boussingault is, in this respect, decisive, clear, and intelligible. The addition of salt to the fodder had no influence on the quantity of flesh, fat, or milk obtained from the animals; "but," says Boussingault, "the salt appeared to have a favourable effect on the appearance and quality of the stock. After the first fourteen days, we observed no perceptible difference between the two lots (each of three oxen); but in the course of the month following, the difference was visible even to the unpractised eye. In

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why in that which is more concentrated, there is left, after the addition of nitric acid, more urea in solution than corresponds to the solubility of the nitrate.

the beasts of both lots, the skin to the feel was fine and sound, but the hair in the oxen which had got salt was smooth and shining, that of the others was dull and erect. On prolonging this experiment, these signs became still more prominent. In the animals of the second lot, after they had had no salt for a year, the hair was matted, and the skin here and there devoid of hair. Those of the first lot, on the contrary, retained the look of stall-kept beasts; their liveliness and frequent indications of the tendency to leap, contrasted strikingly with the heavy gait and cold temperament observed in those of the second lot. There is no doubt," continues Boussingault, "that a higher price would have been obtained in the market for the oxen reared under the influence of salt."

These experiments are most instructive. In the oxen which only had as much salt as was contained in their fodder, the quantity of salt was insufficient for the secretory process. There was wanting the means of transport for a number of substances which, out of the body, excite disgust; their whole frame, the blood, flesh, and all the juices were loaded with these; for the external surface of the skin is a mirror of the state of the interior. The other oxen, which daily had salt added to their fodder, remained healthy, even in the mode of life to which they were confined, which corresponded but little to their nature, and with excess of food and deficient exercise. Their blood remained pure, and well fitted for all the purposes of nutrition. In the salt they had a powerful means of resistance to external causes of disturbance to health, which, in the actual circumstances, was indispensable to them. The body of the others was, in regard to disease, like a fire-place, heaped with the most inflammable fuel, which only requires a spark in order to burst into flame and to be consumed.

Salt does not act as a producer of flesh; but it neutralises the injurious action of the conditions, which must be united in the unnatural state of animals fed or fattened in order to produce flesh; and the advantages attending its use can hardly be estimated too highly.

Many agriculturists, however, have drawn very different conclusions from these experiments. As the addition of salt yields to them (the farmers) no profit, since, by the outlay on salt, nothing is gained in flesh, they concluded that salt is of no use whatever; nay, these experiments have actually been abused, as proofs and arguments against the reduction of the *impost on salt*,—of all taxes on the Continent that which is the most odious, the most unnatural, and the most disgraceful to human reason. We may here see that more wisdom is displayed in the instinct of an ox or of a sheep, than in the arrangements of the being who, strange to tell, often regards himself as the image of Him who is the perfection of all kindness and of all reason.

Besides its chemical characters, common salt possesses a physical property, which gives it a special importance in the vital processes; because those other salts which partake this property with it, are not consumed either by men or animals in their ordinary mode of life.

This most interesting property may easily be rendered visible with the aid of a very simple apparatus.

If, for example, we tie over one opening of a glass-tube, four to six inches long, and about a quarter of an inch wide, with a moist membrane (intestine or bladder, &c.), and fill it to one-half with spring water, and then place it in a glass of the same water, so that the water within and without the tube stands at the same level, we observe, even after hours or days, no change in the level of the two liquids.

But if we now add, to the water in the tube closed with bladder, a few grains of common salt, we shall see, after a few minutes, the water in the tube rise above the level of that in the glass; it moves upwards.

If now we add salt also to the water in the glass, and in such quantity that the proportion of salt in the two liquids is the same, no change of level occurs. But if more salt, in proportion, be added to the water in the glass than to that in the tube, the opposite change takes place: the water in the tube sinks; that in the glass rises.

We see from this, that the spring-water flows towards the saline water, and the weaker solution of salt towards the stronger; as if forced by an external pressure to pass through the pores of the membrane, in opposition to the law of gravitation.

By the mere addition of common salt to the water, the tube with the bladder acquires the property of a pump, and sucks up water with a force which, in many cases, is equal to the presence of a column of mercury, two to three inches in height.

When the tube, closed by a very thin membrane, is half-filled with ox-blood deprived of its fibrine, and placed in a glass of warm water (at about 100° F.), the blood, after a few minutes, rises, just as the solution of salt did. The water flows towards the blood.

That the presence of salts in the liquor sanguinis, has a great share in this suction, we perceive in this, that the liquid, which may easily be obtained by pressure from blood coagulated by heat, and which contains common salt and other salts, when introduced into the tube instead of the blood, exhibits precisely the same phenomena.

The power of the membrane, to cause water to flow towards that side of it on which the salt is found, depends, therefore, on the salt. When the liquids on both sides, contain equal proportions of salt, no flow takes place either way. The liquid invariably flows towards that side where most salt is present, and it flows the more rapidly, the greater the difference in the proportion or per centage of salt between the two liquids.

When we add to the solution of salt *a free alkali* (in the form of carbonate or phosphate), the power of suction is very perceptibly increased; and when the liquid in the outer glass is slightly *acid*, and the solution of salt in the tube is *alkaline*, the flow (of the acid to the alkaline liquid) takes place with the greatest velocity.

Any one who takes the trouble to repeat these attractive experiments will obtain, by the mere contemplation of them, a perfect insight into the essence of the organic process of suction.

In the animal body, indeed, are united all the conditions for rendering the circulating system, by means of the blood, a most perfect suction pump, which performs its duties without stop-cocks or valves, without mechanical pressure, nay, without regular canals or passages for the transmission of the fluids. The solution formed in the digestion of food in the stomach is *acid*, the blood is a *saline* and *alkaline* fluid. The whole digestive or intestinal canal is surrounded by a system of infinitely ramified blood-vessels, in which the blood moves with great velocity. By means of the urinary apparatus, the water which has flowed into the blood is immediately filtered off, and the circulating fluid is thus always kept in the same state of concentration.

We can now easily understand the effects produced on the organism by waters containing different proportions of salt.

If, for example, we drink, fasting, every ten minutes a glass of spring-water, the proportion of salt in which is far below that of the blood, there is passed after drinking only the second glass (each glass being supposed to contain four ounces) a quantity of coloured urine, very nearly equal in bulk to the first glass of water. When in this way twenty glasses have been taken, there have been nineteen evacuations of urine, the last of which is nearly colourless, and in the proportion of salt but slightly exceeds spring-water.

If we make the same experiment with spring-water to which has been added some salt, about as much as the blood contains (from 0·75 to 1·0 per cent.) no unusual evacuation of urine occurs. It is hardly possible to drink more than three glasses of such water; a sensation of repletion, pressure, and weight at stomach indicate that water, having a per centage of salt equal to that of the blood, requires a far longer time for its absorption into the circulation.

Lastly, if we take a solution of salt, the per centage of salt in which is somewhat higher than in the blood, there occurs the opposite of absorption, namely purging.

We see that the absorptive power of the blood-vessels for water varies according to the proportion of salt in the water. If that be less than in the blood, it is absorbed with great rapidity; when the proportion of salt in both fluids is the same, an equilibrium occurs; if the water contain more salt than the blood, this salt-water is expelled, not like the weaker solution, through the kidneys, but through the intestinal canal.*

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* "Common salt has generally become a very great necessity, even for the rudest nations. In not a few countries it is one of the most valuable mercantile commodities. In several countries of Africa, men are sold for salt; among the Gallas and on the coast of Sierra Leone, the brother sells his sister, the husband his wife, parents their children, for salt; in the district of Accra (gold coast) a handful of salt, the most valuable merchandise after gold, will purchase one or even two slaves."

"Only very few nations refrain from the use of salt entirely," (? the author gives no instance of such *entire* abstinence); "or try to supply its place by surrogates." (pp. 1 and 2.) In the northern parts of the hill countries of tropical Africa, salt, in consequence of the long carriage through the desert, becomes so dear, that only the rich can procure it. "Even Mungo Park mentions,

LETTER XXIX.

BREAD and flesh, or vegetable and animal food, act in the same way with reference to those functions which are common to man and animals; they form, in the living body, the same products.

Bread contains, in its composition, in the form of vegetable albumen and vegetable fibrine, two of the

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that among the Mandingoes and other negro tribes in the interior, the expression, '*he flavours his food with salt*,' is synonymous with that of, he is a rich man. Park experienced from the necessity of giving up the use of salt, especially when long confined to vegetable food, a longing after salt, such as he was unable to express in words. Callié also assures us that 'the natives of Rankan are seldom able to use salt with their food on account of its high price, and that it is there an article of luxury.' The Mandingoes and Bambaras use salt only on certain festival days." —(Lehrbuch der Salinenkunde, Karsten, Berlin, 1846, pp. 720, 724, 754, 755.)

"There are countries, where salt must be given to animals to keep them alive. According to Warden, for example, in the northern districts of Brazil, domestic animals died when they did not receive a fixed portion of salt or saline sand; and according to Roulin, when the cattle did not find salt in the plants, in the water, or in the earth, the females became less prolific, and the herd rapidly diminished in number."—(Möglin'sche Annalen, II., 1847, p. 29.)

In a prize essay on the use of salt, crowned by the Academy of Medicine in Brussels, Dr. Le Saine, remarks, that "Salt increases the fertility of the male, and the tendency of the female to conceive, and doubles the power of nourishing the fœtus. During the period of suckling, the salt given to the mother renders the sucking animal stronger, and the milk more abundant and more nutritious. Salt accelerates growth, and renders the wool of sheep finer. The flesh of animals which have had abundance of salt is better flavoured, more nutritious and more easily digested, than that of animals which receive no salt in their food."—(Journal de Chimie Medicale, 1849, p. 127.)

chief constituents of flesh, and, in its incombustible constituents, the salts which are indispensable for sanguification, of the same quality and in the same proportion as flesh. But flesh contains besides these, a number of substances which are entirely wanting in vegetable food; and on these peculiar constituents of flesh depend certain effects, by which flesh is essentially distinguished from other articles of food.

When finely chopped muscular flesh is lixiviated with cold water, and pressed out, there is left a white fibrous residue, consisting of the true muscular fibres of cellular tissue, vessels, and nerves.

When the lixiviation is complete, the water dissolves from 16 to 24 per cent. of the weight of the dry flesh. The fibrine of flesh, the chief constituent of the muscular fibre, constitutes three-fourths of the weight of the lixiviated residue. If this residue be heated to between 158° and 177° F., the fibres contract together, shrink, and become horny and hard; a change, a kind of coagulation takes place, in consequence of which the fibres of flesh lose the power of sucking up water like a sponge, and retaining it. Water flows out, for, without the addition of water the pressed residue, when heated, soon swims in water. The lixiviated flesh, when boiled with water, is, like the water in which it has been boiled, tasteless, or has a slight nauseating taste; it cannot be masticated, and even dogs reject it.

All the savoury constituents of flesh are contained in the juice, and may be entirely removed by lixiviation with cold water.

When the watery infusion of flesh thus obtained, which is commonly tinged red by some of the colouring matter of blood, is gradually heated to boiling, the *albumen of flesh* separates, when the temperature has risen to 133°, in nearly colourless cheesy flocculi; the colouring matter of the blood is not coagulated till the temperature rises to 158°. The liquid is now pale yellowish, clear, and it reddens litmus paper, proving the presence of a free acid.

The proportion of the *albumen of flesh* separated as a coagulum by heat is very various, according to the age of the animal. The flesh of old animals often yields no more than 1 to 2 per cent.; that of young animals as much as 14 per cent.

The infusion or extract of flesh, after being freed by boiling from albumen and the colouring matter of blood, has the aromatic taste, and all the properties of the soup made by boiling the flesh. When evaporated, even at a gentle heat, it becomes darker coloured, finally brown, and acquires the flavour of roast meat. When dried up, there is obtained a brown, somewhat soft mass, amounting to 12 or 13 per cent. of the weight of the original flesh (supposed to be dried). This extract is easily soluble in cold water, and when dissolved in about thirty-two parts of hot water, with the addition of some salt, gives to this water the taste and all the peculiar properties of an excellent soup. The intensity of the flavour of the dry extract of flesh is very great; none of the means employed in the kitchen is comparable to it in point of flavouring power.

The residue of flesh after exhaustion with cold water, is of the same quality in different animals; so that it is impossible in this state to distinguish beef from poultry, venison, pork, &c.

On the other hand, the soup made of the flesh of different animals possesses, along with the common flavour in which all soups resemble one another, in each case a peculiar taste, which distinctly recals the smell or taste of the roasted flesh of animals; so that if we add to the boiled and exhausted flesh of roe-deer the concentrated juice of beef or poultry, the meat thus prepared cannot now be distinguished by its flavour from roast beef or fowl.

The fibre of meat is, as we see from these facts, in its natural state, steeped in and surrounded by a liquid containing albumen; and the tender quality of boiled or roasted meat depends on the amount of the albumen deposited in its substance, and there coagulating, whereby the contraction, toughening, and hardening of the fibres is prevented. Meat is underdone or bloody when it has been heated throughout only to the temperature of coagulating albumen, or 133°; it is quite done, or cooked, when it has been heated through its whole mass to between 158° and 165°, at which temperature the colouring matter of the blood coagulates.

From these considerations we may deduce certain conclusions, not without importance, for the preparation of animal food; which, on account of the universal interest attaching to them, are perhaps worthy of being pointed out.

If the mass of flesh intended to be eaten be introduced into the boiler when the water is in a state of brisk ebullition; if the boiling be kept up for a few minutes, and the pot then placed in a warm place, so that the temperature of the water is kept at 158° to 165°, we have united the conditions for giving to the flesh the qualities which best fit it for being eaten.

When it is introduced into the boiling water, the albumen of the flesh is immediately coagulated on the surface, and to a certain depth inwards, thus forming a skin or shell, which no longer permits the juice of the meat to flow out, nor the water to penetrate into the mass. The flesh continues juicy, and as well flavoured as it can possibly become. The greater part of the savoury constituents is retained in the meat.

On the other hand, if the mass of flesh be set on the fire with cold water, and this slowly heated to boiling, the flesh undergoes a loss of soluble and savoury matters, while the soup becomes richer in these. The albumen is gradually dissolved from the surface to the centre; the fibre loses, more or less, its quality of shortness or tenderness, and becomes hard and tough. The thinner the piece of flesh is, the greater is its loss of savoury constituents.

This explains the well-known observation, that that mode of boiling which yields the best soup, gives the driest, toughest, and most vapid meat; and that, in order to obtain well-flavoured and eatable meat, we must relinquish the idea of making good soup from it.

If finely-chopped flesh be slowly heated to boiling with an equal weight of water, kept boiling for a few minutes, and then strained and pressed, we obtain the very strongest and best flavoured soup which can be made from flesh. When the boiling is longer continued, some little additional organic matter is dissolved, but the flavour and other properties of the soup are, thereby, in no degree increased or improved. By the action of heat on the fibres, a certain amount of water or juice is always expelled from them; whence it happens that the flesh loses weight by boiling, even when immersed in water (as much as 15 per cent. of the weight of the raw flesh). In larger masses this loss is not so great.

Even in roasting meat, the heat must be strongest at first, and it may then be much reduced. The juice which, as in boiling, flows out, evaporates, in careful roasting, on the surface of the meat, and gives to it the dark brown colour, the lustre, and the strong aromatic taste of roast meat.

The constituents of the juice of flesh and of the soup are very numerous, and only imperfectly known; but what we do know of them is sufficient to excite much interest. There is no part of the body more complex than the tissue we call muscle. Innumerable nerves, and minute vessels filled with coloured and colourless fluids, are ramified through the true muscular substance. That which we remove by lixiviation with water,—the juice,—contains the soluble matters of the whole tissue. Soup, like the flesh itself, is of a very complex nature. Most of its constituents are very rich in nitrogen: two of them, *kreatine* and *kreatinine*, may be obtained in fine, colourless, transparent crystals. The juice of flesh, or the soup, is particularly rich in incombustible matters, which constitute upwards of one-fourth of the weight of the dry extract of flesh.

The free acid of the juice of flesh or of soup appears to be formed in consequence of a change which begins very quickly after death, or is effected by boiling. The muscles of animals just killed, before the occurrence of the stiffness that follows death, do not redden blue litmus paper.

Kreatine is what is called an indifferent substance, but only in the sense that it plays neither the part of an acid nor that of a base.

Kreatinine, on the other hand, which occurs in the juice of flesh in much smaller quantity than kreatine, is a powerful organic base. It connects itself with the series of the nitrogenised organic bases of the vegetable kingdom, among which are found the most terrible poisons and the most active remedies; it has an alkaline reaction, and forms crystallisable salts with acids; it is found only in animal organisms. Kreatine and kreatinine are products of the vital process, and constituents of the flesh of all vertebrata hitherto examined. Human flesh is particularly rich in kreatine. These two bodies are closely related to each other; they contain the same elements in the same proportion, excepting a certain amount of oxygen and hydrogen, but kreatine contains the elements of four equivalents of water more than kreatinine. Each may be converted into the other. In contact with a strong acid, kreatine loses the elements of four equivalents of water, and kreatinine is produced, which neutralises a part of the acid. Kreatinine, when in the act of separating from its combination with chloride of zinc, takes up water, and is re-converted into kreatine.*—(Heintz.)

The occurrence of these two bodies, and the relation between them, lead to the suspicion that they possess some significance in regard to the vital process; and it would appear especially as if some effect were connected with the conversion of kreatine into kreatinine.

From the juice of flesh (of ox heart) there have also been obtained, by distillation with sulphuric acid, small quantities of volatile acids, butyric, acetic, and formic acids; and, from the residue, inosite, a non-nitrogenous body, having the same composition as milk-sugar, but differing from it in many properties (Scherer); also, a non-nitrogenous acid, identical in composition with, and very similar to, lactic acid, but differing from it in its salts; and a nitrogenous acid, inosinic acid, especially in the juice of the flesh of fowls, turkeys, &c.

All these substances constitute but a small part of the extract of flesh. By far the greater part of it consists of uncrystallisable compounds, the properties of which have not yet been sufficiently studied, so that we do not know how to separate them from one another. To these substances belong the savoury constituents of the juice of flesh, and those among them which become so easily brown when gently heated; and a substance which agrees with gelatine in the property of being precipitated in thick glutinous flocks by tannine or an infusion of nut-galls. In the lixiviated residue of flesh no uric acid, and in the aqueous extract of flesh neither uric acid nor urea, can

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* In a solution of kreatinine not quite pure, which stood for several months in a cupboard, the whole of the kreatinine gradually changed into kreatine, which was deposited in a single fine large crystal; a slight mouldiness also appeared.

be detected; which seems to indicate that these products of the change of matter, which are destined for excretion, are removed as rapidly as they are formed. The juice of flesh also contains, as was formerly stated, a compound of chlorine, not chloride of sodium (common salt), but chiefly chloride of potassium. This is the more remarkable, because the blood which circulates in the muscles contains proportionally so much common salt.*

The juice of flesh contains, beyond a doubt, the conditions necessary for the formation of the whole muscle, and for the production of its peculiar properties. In the albumen of this fluid, we have the substance serving as transition-product to the fibrine of flesh, and in the other substances the matters required for the production of cellular tissue and nerves.

The juice of flesh contains the food of the muscles; the blood, the food of the juice of flesh. The muscular system is the source of all the manifestations of force in the animal body; and in this sense we may regard the juice of flesh as the proximate condition of the production of force.

From this point of view it is easy to explain the effect of soup. Soup is the medicine of the convalescent. No one estimates its value more highly than the Hospital physician, for whose patients soup, as a means of restoring the exhausted strength, cannot be replaced by any other article of the Pharmacopœia. Its vivifying and restoring action on the appetite, on the digestive organs, the colour, and the general appearance of the sick, is most striking.

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* In the muscles, especially those of the neck, of an alligator, which had died of a disease the nature of which cannot now be ascertained, and which was obtained for the Anatomical Museum of Giessen, the flesh had a peculiar stained or spotted appearance, and on close examination it appeared that this arose from innumerable minute crystals of uric acid, deposited between the primary bundles of muscular fibre and the cellular tissue.

It is evident that the constituents of the blood, which are so different from those of the juice of flesh, must undergo a whole series of changes before they acquire the form and quality adapted to the production of the living muscle, before they become constituents of the juice of flesh. In flesh we eat these products, prepared, not in our own organism, but in another, and it is extremely probable that they, or a part of them, retain, when introduced into a second organism, the power of causing the same changes, and producing the same effects as in that organism in which they were formed.

Herein consists, obviously, the high value of flesh, taken as a whole, as an article of food. Hay and oats, potatoes, turnips, bread, &c., produce in the living body blood and flesh; but none of all these substances reproduces flesh with the same rapidity, or restores the muscular substance, wasted by work, with so small an expenditure of organic force as animal food.

Sagacious and experienced physicians, and of these especially Parmentier and Proust, have long ago endeavoured to procure a more extended application of the extract of meat. "In the supplies of a body of troops," says Parmentier, "extract of meat would offer to the severely wounded soldier a means of invigoration, which, with a little wine, would instantly restore his powers, exhausted by great loss of blood, and enable him to bear the being transported to the nearest field hospital." "We cannot," says Proust, "imagine a more fortunate application. What more invigorating remedy, what more powerfully-acting panacea than a portion of genuine extract of meat, dissolved in a glass of noble wine? The most *recherché* delicacies of gastronomy are all for the spoiled children of wealth! Ought we then to have nothing in our field hospitals for the unfortunate soldier, whose fate condemns him to suffer, for our benefit, the horrors of a long death-struggle amidst snow and the mud of swamps?"

Now, when science has made us better acquainted with the nature and quality of the juice of flesh, it appears to be truly a matter of conscience, again and again to recommend to the attention of governments the suggestions of these noble-hearted men.

In Podolia, in Buenos Ayres, in Mexico, in Australia,* and in many parts of the United States, where beef or mutton has only a nominal value, we could, with the simplest means, collect immense quantities of the best extract of meat, the importation of which might perhaps acquire a very peculiar importance for the potato-eating population of Europe. For the numerous hospitals of the Continent, and their unfortunate tenants, this extract would replace the soup; and the physician would, by its means, be enabled to prescribe at all times, and under all circumstances, soup of uniform quality, and of any given strength.

The experiment has several times been made, of manufacturing extract of meat on the large scale where meat is very cheap, and of making from it, under the name of portable soup-tablets, an article of commerce. But the product of these manufactories did not become popular; and was not used in hospitals, where it ought to have been most advantageously employed. The cause of this was in the article itself. It was too dear, and it was soon discovered that it had not the

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* Mr. James King, one of the most intelligent colonists of Australia, who has most highly distinguished himself in regard to the cultivation of the vine in that quarter of the globe, writes to me as follows:—"Irrawang, near Raymond Terrace, New South Wales, 26th October, 1850. This district is an excellent and widely extended pasture country. Cattle and sheep are abundant and cheap. Thousands of them are slaughtered every month, and the flesh is boiled down to obtain the fat. The nutritious part of the flesh is thrown away as worthless. The best beef costs no more than one halfpenny per pound."

properties and the effects of soup. The inferior quality of these soup tablets was chiefly caused by an entirely erroneous view which was entertained concerning the cause of the good effects of soup. It had been long observed that soup made by boiling from meat, when concentrated to a certain point, gelatinises, or forms a jelly, like all strong and highly-flavoured sauces or stock; and people, without any sufficient reason for doing so, adopted the opinion that the substance (gelatine) which attracted the eye most was also the most efficient and important, indeed, the chief constituent of good soup. Thus it came to pass, by degrees, that people took the gelatinising matter for the true soup; and as the manufacturers of the tablets soon found that the best meat did not yield the finest tablets—that white meat made them harder, and more easily preserved—and that tendons, feet, cartilage, bones, ivory, and hartshorn, yielded the most beautiful and most transparent jelly-tablets, which were cheaply obtained, and sold at a high price, ignorance and the love of gain exchanged the valuable constituents of flesh for gelatine, only to be distinguished from common joiner's glue by its high price. It was no wonder that such a product failed in acquiring a hold on the public mind.

The erroneous notion that gelatine was the active principle in soup, led at last to the experiment, in the Hospital of St. Louis, at Paris, of replacing the true genuine meat soup, to the extent of one-half by gelatine obtained from bones by long boiling. But from that time the action of gelatine became an object of research to scientific men (Douné); and the facts ascertained by them led to a conflict of opinions, and, in consequence of this, to valuable researches (among which those of a commission of the French Academy, with Magendie at its head, must be particularly pointed out,) on the nutritive power of gelatine, and on nutrition generally, by which the early errors were corrected, and a number of new facts fixed and gained concerning the nutritive values of many articles of food, animal and vegetable. It has now been proved, by the most convincing experiments, that gelatine, which by itself is tasteless, and when eaten excites nausea, possesses no nutritive value; that, even when accompanied by the savoury constituents of flesh, it is not capable of supporting the vital process, and when added to the usual diet as a substitute for plastic matter, does not increase, but on the contrary diminishes the nutritive value of the food, which it renders insufficient in quantity and inferior in quality; and that its use is hurtful rather than beneficial, because it does not, like the non-nitrogenous substances provided by nature for respiration, disappear in the body without leaving a residue, but overloads the blood with nitrogenous products, the presence of which disturbs and impedes the organic processes.

We now know that the active ingredients of soup are found ready formed in the aqueous infusion of flesh, and are not products of the culinary operations, and that the gelatine of soup is formed by long boiling of the flesh, from the cellular membrane of the muscular tissue. Since these things have been ascertained, the use of gelatine as a nutritive and invigorating substance has been entirely given up; and it only retains a place in the domain of unscientific cookery, in the form of mucilaginous or gelatinous soups, not very attractive to the palate, made in China from the air-bladder of fishes, and in England from the flesh of turtle; articles of diet which are a fertile source, although seldom justly appreciated in this view, of disturbance in the digestive process.*

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* It need hardly be pointed out specially, that those who may feel inclined to prepare extract of meat as an article of commerce,

Experience has taught us that the nutritive value of ordinary boiled meat is lessened when it is taken without the soup, and direct experiments have proved that meat thoroughly boiled and lixiviated hardly retains any nutritive value at all. In the experiments of the French Academicians, a dog, weighing 12·6 lbs., which was fed daily with a ½ lb. of boiled flesh, softened in water, thoroughly expressed and freed from fat as much as possible, lost, in the course of 43 days, one-fourth of his weight. After 55 days his emaciation was extreme; he could hardly eat the fourth part of his ration, and his utter exhaustion was evident to the eye. The animal, however, continued lively, his hair was shining, and he showed in no respect the symptoms of consumption from disease, but rather looked like an animal which had good food, but in a quantity far inferior to his wants. On the other hand, dogs fed daily with the same weight of raw flesh (which contains more water and less solid matter than boiled meat) of the poorest quality (sheep's head), exhibited, after 120 days, no signs of disturbance in health, and retained their full weight. It is certain that the first dog, also, would have

will entirely miss their aim, unless they most carefully and conscientiously seek to avoid the errors of those who have hitherto attempted it. Half an hour's boiling of the chopped meat with eight or ten times its weight of water, suffices to dissolve all the active ingredients. The decoction must, before it is evaporated, be most carefully cleansed from all fat (which would become rancid), and the evaporation must be conducted in the water bath. True extract of meat is never hard and brittle, but soft, and it strongly attracts moisture from the atmosphere. The boiling of the meat in the first instance may be carried on in clean copper vessels, but for the evaporation of the soup, vessels of pure tin, or still better, of porcelain, should be employed. If the price of the extract should be found not to exceed about three shillings per pound, it would certainly become a most profitable commodity. In Giessen, without reckoning the cost of preparation, the extract of meat cannot be produced for less than from six shillings to seven shillings and sixpence per pound in meat alone.

continued healthy, if he had been fed with the meat thoroughly boiled, but not lixiviated, and had got at the same time the soup formed in boiling it; and thus the loss of nutritive power in the flesh was obviously caused by the removal of the ingredients of the soup.

No one of all the *organic* constituents of the soup or juice of flesh constitutes a part of the blood, as far as our present knowledge extends. We assume that these substances can contribute to the reproduction of muscle in the living body, but they are incapable of conversion into the albumen or the fibrine of the blood. Neither can they be regarded as essential conditions of the digestive and nutritive process, because milk and vegetable food possess full nutritive value, without containing a substance analogous to these compounds.

It cannot, therefore, be maintained that the loss of nutritive value in lixiviated flesh is caused by the removal of the soluble organic constituents of the juice; and we must consequently look for the cause of this phenomenon in the incombustible constituents of the soup or the juice of flesh.

A glance at the analyses of the ashes of flesh, of the juice of flesh, and of the boiled and lixiviated meat, suffices to show that in the boiling and lixiviation of the flesh, by far the greater part of the salts enters into the soup.

Now, if we compare the ashes of flesh with those of the blood of the carnivora, we find that, with the exception of the common salt in the blood, they contain the same elements, very nearly in the same absolute quantity and the same relative proportion. Flesh contains the salts of the blood, and, as is proved by the results of a flesh diet, in a proportion well adapted for sanguification, and such as in no way disturbs the vital operations.

But when flesh is exhausted by boiling and lixiviation, these salts are divided into two portions; the residual meat contains a far smaller proportion of salts than the blood.

Fresh meat, when incinerated, leaves 3½ per cent. (of the weight of the dried flesh) of salts. Meat exhausted by boiling leaves hardly 1 per cent. 10 lbs. of fresh meat yield, in all, 42·93 grammes (2½ oz. avoirdupois, or 662·8 grains); but when these 10 lbs. are exhausted, by lixiviation and boiling, 544·7 grains of the 662·8 grains enter the soup, and there remain in the meat only 118 grains. The fresh meat contains, in its ash, upwards of 40 per cent. of potash, the exhausted flesh only 4·78 per cent. of that alkali.*

The whole amount of salts in the flesh would have been necessary, and would have sufficed, to form, with the fibrine and albumen of the flesh, blood of the same quality as that already present in the body; and it is perfectly clear, that by the loss of ⅘-ths (82 per cent.) of these salts, indispensable to sanguification, the flesh lost so much of its value in the

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* Composition of the ashes of flesh, acccording to Keller :—

Phosphoric acid	36·60
Potash	40·20
Earths and oxide of iron	5·69
Sulphuric acid	2·95
Chloride of potassium	14·81
	100·25

	When boiled, there enter into the *soup*,	And there remain in the *exhausted meat*,
Phosphoric acid	26·24	10·36
Potash	35·42	4·78
Earths and iron	3·15	2·54
Sulphuric acid	2·95	"
Chloride of potassium	14.81	"
	82·57	17·68

The soup contains 0·46, the residue 1·42, of phosphate of iron.

formation of blood. The deficiency of salts did not destroy in the flesh the property of undergoing a transformation in the body; but its chief constituents (the fibrine and albumen of flesh) could not become constituents of the blood, for want of the necessary conditions; and the flesh, becoming a respiratory material (and a very imperfect one) lost, in a great measure, its nutritive power. Its sanguific value was lessened with the amount of salts removed, and, probably, quite as much in consequence of the circumstance that the relative proportions of the individual salts left in the meat, after the division into soluble and insoluble, effected by the action of the water, was very ill adapted for sanguification. The exhausted meat contains in its ashes upwards of 17 per cent. of phosphoric acid beyond the amount required to produce, with the bases present, salts of an alkaline re-action, such as are indispensable to blood. By a division of the salts of this ash (of exhausted meat) into an acid salt, which we may suppose to be excreted by the kidneys, and a salt of alkaline character, capable of serving for sanguification, the efficient quantity of salts in that ash must, of course, be still further diminished.*

We can now understand the cause of the loss of

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* Food which, like the yolk of hen's eggs, contains, in its ashes, potash and phosphoric acid in the same proportion as the acid phosphates (PO_5, MO), cannot possess, since such a division as indicated in the text is no longer possible, any sanguific value, if given by itself, without other food. Magendie reports, in his experiments; "As we had plenty of yolks of eggs at our command, we wished to try if dogs could be fed on them. For this purpose we gave twelve or fifteen hard-boiled yolks to young dogs with excellent appetites. On the first day the yolks were eaten, although with some signs of repugnance; on the second, this was still more decided; and on the fourth, the animals, though in the highest degree hungry, would not touch them." The yolk constitutes 40, the white 60 per cent. of the egg; the former contains 1·5 per cent. the latter only 0·65 per cent. of incombustible matter.

nutritive value in salted meat, as well as the influence of an exclusive salt-meat diet on the quality of the blood and of the juices. Every housewife knows that fresh meat, sprinkled with dry salt, without the addition of a drop of water, is found, after a few days, swimming in brine, and that the weight of meat diminishes considerably when laid in brine, while the water increases. Fresh meat, in fact, contains more than three-fourths of its weight of water, which is retained in it as in a sponge. But the power of flesh to absorb and retain brine is far less considerable. In similar circumstances, it only takes up into its pores half as much of saturated brine as of water. Hence it happens, that fresh meat, in contact with dry salt, allows water to flow out, because its water becomes brine. But this expelled water, which is found surrounding the meat, is not pure water, but juice of flesh—soup, with all its active ingredients, organic and inorganic. Flesh, by salting, loses in point of nutritive value, in consequence of the removal and division (into two parts, soluble and insoluble) of the salts indispensable to sanguification, which are present in it, in the same way, if not to the same degree, as when boiled. Of 3 cwts. of meat, by the full action of salt, 1 cwt. may be rendered useless for the vital process, and converted into an inferior respiratory material. This loss may be counteracted (as has been, indeed, tried with success) by evaporating the brine till the salt crystallises out, and adding the syrupy mother liquor (which represents a very concentrated solution of extract of meat) to the salted meat, after it has been boiled tender, to be taken with it. It would, obviously, be more convenient, but, of course, more expensive, to restore the ingredients of the juice to the salted meat in the form of pure extract of meat.

Flesh contains, in its composition, certain universal conditions of digestion and nutrition, in regard to which other kinds of animal or vegetable food resemble it. In its fibrine and albumen, it has a definite value for the production of the fibrine and albumen of blood ; in its fat it possesses a value for the production of heat, and in its salts a value for the production both of blood and of heat, as well as for the secretory processes. In addition to these, flesh possesses, in the very remarkable peculiar constituents of the juice, a peculiar value for certain processes of a higher order, by which it is distinguished from all other forms of animal food.

All kinds of flesh are not equal in these different values. Veal, for example, is totally different from beef in respect to the proportion of the salts contained in both. The amount of ashes, indeed, is nearly equal in veal and beef, but the beef is much richer in alkalies. Among the inorganic constituents of veal * we find upwards of 15 per cent. of phosphoric acid more than is required to form alkaline salts with the bases present (salts of the formula, PO_5, 2 MO); it contains proportionally little of the easily digestible fibrine of flesh. The greater part of the fibre of veal consists of a substance resembling the fibrine of blood, which, in water acidulated with hydrochloric acid, swells up, without dissolving. Veal is also rich in soluble cellular tissue (gelatine), and usually contains very little fat.

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* Analysis of the ashes of veal, by Staffel (after deducting common salt).

Phosphate of potash	68·05	PO_5, 2 MO	73·71
Phosphate of Soda	5·66		
Phosphate of Lime	3·72	„ „	9·97
Phosphate of Magnesia	6·21		
Free Phosphoric acid			15·10
Peroxide of iron			0·30
Silicic acid			0·92
			100·99

Beef, according to Staffel, contains 1·06 per cent. of peroxide of iron.

Veal is further very essentially distinguished from red meat, such as beef, by its containing much less iron.

Among the inorganic substances in blood, iron, in the form of oxide, is a chief constituent. It constitutes (after deducting the common salt) more than 20 per cent. of the whole ash of blood; and the constancy of its occurrence, as well as its large proportion in the blood, indicates sufficiently the high value which it must possess for the vital operations.

Iron is one of the chief constituents of the colouring matter of the blood, and, consequently, of the blood corpuscles. These corpuscles are essential to all the actions of the blood; they effect the exchange of gases in respiration, the whole change of matter, the production of heat and of force in the body. The energy and intensity of these processes bear a very definite relation to the number of blood corpuscles, and, through these, to the amount of iron in the blood. There are diseases, such as many cases of chlorosis, in which the number of corpuscles is diminished by one-fourth, and the proportion of iron in the ashes of the blood in the same proportion; and experience has shown that the symptoms, in such cases (great bodily weakness and weariness, pale aspect, and deficient heat), may be entirely removed, and health restored, by small doses of the salts of iron.

The function of iron, and the indispensable necessity for iron in the food, is obvious from these considerations. We cannot imagine the formation of blood globules without iron. A strong, nutritious diet must contain, under all circumstances, a certain amount of iron, corresponding to the quantity which daily becomes worn out or inactive, and is excreted by the intestinal canal. It is quite certain that, if iron be excluded from the food, organic life cannot be supported.

Vegetable food, especially grain, and, of course, bread, contain as much iron as beef, or red meat generally. Veal contains only one-third of the iron that beef does. Cheese, eggs, and especially flesh, contain, in proportion to the alkalies, a quantity still smaller than veal.

Milk (which contains only 0·47 per cent. of iron in its ashes), cheese, eggs, and fish, belong to those articles of food which may be used in fasting, as is practised in the Roman Catholic Church; and it is in the highest degree probable that the effects aimed at in religious prescriptions and rules by the exclusion of flesh, and especially of red meat, are to be accounted for by the deficiency of iron.*

The other incombustible constituents of fish are the same as those of beef. When fish is boiled, a part of the soluble ingredients is taken up by the soup, which is usually not eaten, and the sanguific value of the fish is thus diminished. The nutritive value of dried and salted fish, which, before being eaten, must be steeped in water and washed, is peculiarly low. †

* Ashes of Cheese, deducting common salt, by Johnson:—

	Cheese made with rennet. Gruyère.	Cheese from sour milk. German hand-cheese.
Alkalies . . .	13·48	42·69*
Lime	39·22	8·92
Magnesia . . .	1·77	,,
Peroxide of iron . .	0·35	0·40
Phosphoric acid . .	45·00	47·88
Silicic acid . .	0·18	0·11
	100·00	100·00

† Ashes of Salt Cod, watered with lime-water and lixiviated. (Zedeler.)

Phosphoric acid . .	16·775	Brought forward .	
Soda	4·259	Oxide of iron . .	0·537
Potash . . .	3·700	Sulphuric acid . .	1·643
Lime	40·218	Carbonic acid . .	13·555
Magnesia . . .	3·272	Common salt . .	15·112
Carried forward .		Total . .	99·071

100 parts of the dried fish left 7·25 per cent. of ashes.

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* Of these alkalies, 25.68 parts are soda, most probably formed by decomposition of common salt in the ashes during incineration, for milk contains no salts of soda, or mere traces of such salts.

In many parts of Germany the stockfish (dried and salted cod) is steeped in lime-water, and instinct has, in this case, discovered the means which science would point out of retaining in the food a large proportion of the phosphoric acid in the form of bone earth; just as this sure guide of man and animals has taught us how to counteract the defects of veal, fish, and eggs, as food by the addition of vegetables, potatoes, or salad. Kitchen vegetables, in this point of view, fill up many blanks. The quantities of salts, of alkalies, and alkaline earths, contained in many of these, excites astonishment. Celery contains from 16 to 20 per cent., common salad 23 to 24 per cent., and cabbage-heads (buds) 10 per cent. of the weight of the dry plant, in the form of incombustible salts.

In order to form a clear idea of the nutritive value of caseine, of the fibrine of blood, and of the gelatinous tissues, it is necessary to consider their composition from a more elevated point of view.

If we arrange the constituents of the animal body, which form the chief part of its mass, as well as caseine, and the ultimate products of the change of matter, according to the amount of nitrogen they contain, and its proportion to the carbon, and if we place first those which contain least nitrogen, we obtain the following series:—

		Equivalents.			Equivalents.	
1. Albumen of blood . .	contains	1	of Nitrogen	for	8	of Carbon.
2. Albumen of flesh . . .	,,	1	,,	,,	8	,,
3. Albumen of eggs . . .	,,	1	,,	,,	8	,,
4. Fibrine of flesh . . .	,,	1	,,	,,	8	,,
5. Caseine	,,	1	,,	,,	8	,,
6. Chondrine	,,	1	,,	,,	8	,,
7. Fibrine of blood . . .	,,	1	,,	,,	7¾	,,
8. Horny tissue and hair . .	,,	1	,,	,,	7	,,
9. Gelatinous tissues, membranes . . .	,,	1	,,	,,	6½	,,
10. Inosinic acid	,,	1	,,	,,	5	,,
11. Glycocoll	,,	1	,,	,,	4	,,
12. Kreatine and Kreatinine .	,,	1	,,	,,	2⅔	,,
13. Uric acid	,,	1	,,	,,	2½	,,
14. Allantoine	,,	1	,,	,,	2	,,
15. Urea*	,,	1	,,	,,	1	,,

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* Of the substances in the above series, the albumen of the

The series of the nitrogenous compounds formed in the body, begins with Albumen and ends with Urea.

Albumen is the highest, urea the lowest compound in the series. The vegetable organism builds up higher or more complex out of lower and less complex compounds. In the circuit of animal life, the higher are resolved into lower compounds. Those compounds, reckoning downwards from albumen, contain the nitrogen of that body; they are derived from albumen under the influence of oxygen, by the gradual elimination of carbon or of a compound of carbon, and for these substances the vital process in the animal body is one of reduction to less complex organic molecules and to inorganic compounds. From inosinic acid, downwards, the compounds have no longer an organised form. Glycocoll, uric acid, allantoine, and urea, are crystallisable; that is, their form is determined by an inorganic force.

We now see how, from the fibrine of flesh, fibrine of blood, or from the latter, the substance of membranes and cellular tissue may be formed; but from gelatine or the fibrine of blood no albumen can be produced. The lower may be formed from the higher, but not the higher from the lower compound; for such a

blood, of eggs, and of flesh, as well as the caseine of milk, have been already frequently mentioned in these Letters. *Chondrine* is the organic matter of bones before ossification; it resembles gelatine in many properties, but differs from it essentially in composition. *Glycocoll* is very remarkable on account of its properties. Although neither acid nor alkaline, it yet plays the part both of an acid, and of a base. It may be obtained from gelatine, cholic acid, and hippuric acid, and may be regarded as coupled with other substances in these compounds. Cholic acid is a chief constituent of bile; hippuric acid, uric acid, allantoine and urea, are constituents of urine. Horny tissue is not a single compound. When horny shavings are left, covered with water in a warm place, they putrefy, and the substance of them is resolved into two products, one of which has some resemblance to caseine, the other to albumen; but both differ in composition from these bodies.

process of construction, rising in the scale, is in contradiction to the forces acting in the animal organism.

We are able, with the co-operation of the same conditions as prevail in the animal body, to produce allantoine from uric acid, urea from kreatine and uric acid; and we have every reason to believe that we shall in time be enabled to form uric acid and urea from gelatinous tissues, and the substance of membranes from the fibrine of blood, just because these are compounds standing lower in the organic scale than those from which they are to be produced. The laws of destruction are always first ascertained; and whether we shall ever learn those of construction is a question which must for the present remain unanswered.

It is frequently asserted, and has been said in these letters, that albumen and caseine are identical. This is not strictly accurate; for it is only the fibrine of flesh and the albumen of blood that are identical in composition; the albumen of eggs differs from these, since it contains, for the same amount of the other elements, one-half more *sulphur*. It is certain that this sulphur must be separated when the albumen of eggs is converted into albumen of blood. Caseine exhibits a similar relation, but reversed. For the same amount of sulphur it contains more carbon, hydrogen, and nitrogen, than the albumen of blood; and it is absolutely certain that a compound containing carbon, hydrogen, and nitrogen, must be separated from this constituent of milk, when it is converted into albumen of blood in the body of the young animal; because in no other way can it yield a compound containing more sulphur than itself.

Of the two acids of the bile, one, the *choleic acid*, contains sulphur. It is quite certain that this compound of sulphur is derived from the fibrine and albumen of blood, which contain sulphur, and not from the substance of membranes, or the cellular tissue, which contain no sulphur.

If now, taking the mean of the best analysis yet made, we express, in equivalents of their elements, the composition of the chief constituents of the animal body, of caseine, and of the constituents of the bile and the urine, we find that these stand in the following relations to one another.

In the		Sulph. *eqs.*	Nitr. *eqs.*	Carb. *eqs.*	Hydn. *eqs.*	Ox. *eqs.*
Albumen of Blood ————of flesh Fibrine of Flesh	there are found for	2	27	216	169	68*
Albumen of Eggs	„	3	36	216	169	68
Caseine	„	2	36	288	228	90
Fibrine of Blood	„	2	40	298	228	92
Chondrine	„	–	9	72	59	82
Gelatinous Tissue	„	–	13	82	67	32
Choleic Acid	„	2	1	52	45	14
Cholic Acid	„	–	1	52	43	12
Uric Acid	„	–	4	10	4	6
Urea	„	–	2	2	4	2

There is nothing hypothetical in these formulæ; they are the expression, in numbers, of certain facts,

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* Composition of

According to the above	Albumen of Blood.		Caseine.		Fibrine of Blood.	
	Formula.	Analysis.	Formula.	Analysis.	Formula.	Analysis.
Sulphur	1·3	1·30	0·9	0·9	0·98	1·0
Carbon	53·5	53·50	53·7	53·6	53·4	53·2
Nitrogen	15·6	15·50	15·7	15·8	16·8	17·2
Hydrogen	7·0	7·16	7·1	7·1	6·8	6·9
Oxygen	22·6	22·54	22·6	22·6	22·2	21·7
	100·0	100·00	100·0	100·0	100·0	100·0

Composition of

According to the above	Chondrine.		Gelatinous Tissue.	
	Formula.	Analysis.	Formula.	Analysis.
Carbon	49·3	49·2	49·3	49.4
Nitrogen	14·4	14·6	18·3	18·5
Hydrogen	6·9	6·9	6·9	6·9
Oxygen	29·4	29·3	25·2	25·2

The accuracy of the formula for cholic and choleic acids has been proved by Dr. Strecker, and that of those of uric acid, allantoine, and urea, by Prout and others.

and as true as analysis can be in the present state of science. They have the advantage of enabling us to perceive at a glance the variations in the composition of these different bodies. But they contain perhaps something more than this.

If we could know with certainty that these formulæ for albumen, fibrine of blood, caseine, chondrine, and gelatine, were not only the most exact expression of the relative proportions of their elements, which they really are, but also correct expressions for the *absolute number* of equivalents of these elements in one *atom* or molecule of these substances, they would be well adapted to give us a profounder insight into the essence of the nutritive process and of the change of matter, than we have hitherto been able to obtain.

A few hints will suffice to illustrate what is meant.

If, for example, we deduct from the formula of caseine in the preceding table, that of the albumen of blood, which we know to be derived from it, we obtain the following result:—

	Sulphur.	Nitrogen.	Carbon.	Hydrogen.	Oxygen.
	eqs.	*eqs.*	*eqs.*	*eqs.*	*eqs.*
From the Formula of Caseine	2	36	288	228	90
Deduct that of Albumen of blood	2	27	216	169	68
There remain	–	9	72	59	22

According to our analysis, we perceive that certain proportions of carbon, hydrogen, nitrogen, and oxygen, must separate from caseine, if it is to be converted into the albumen of blood. But it may perhaps excite astonishment when we observe, that the eliminated elements, with the exception of a certain amount of oxygen, are in the very same proportion as in chondrine, so that if we add to the formula of caseine

10 eqs. of oxygen, we obtain a formula which includes precisely those of the albumen of blood and of chondrine.

	Sulphur.	Nitrogen.	Carbon.	Hydrogen.	Oxygen.
	eqs.	*eqs.*	*eqs.*	*eqs.*	*eqs.*
The formula of Chondrine is	–	9	72	59	32
Add the formula of Albumen of Blood	2	27	216	169	68
Together	2	36	288	228	100
= the formula of Caseine	2	36	288	228	90
+ 10 eqs. of oxygen	–	—	—	—	10

We may perhaps be justified in drawing from these considerations the conclusion, that nature supplies the young animal in milk not only the chief constituent of its blood, but also the material for the formation of its bones, ready formed.

The following comparisons will be found not less striking:—

The formula of Albumen + 10 eqs. of water	contains the elements of	2 Gelatine, and 1 Choleic Acid.
The formula of Fibrine of Blood + 8 eqs. of water	"	1 Albumen of Blood. 1 Gelatine.
The formula of Chondrine	"	1 Cholic Acid. 2 Uric Acid. 8 Water.
The formula of Gelatine + 10 eqs. of water	"	1 Cholic Acid. 3 Uric Acid. 12 Water.
The formula of Albumen + 10 eqs. of Water + 56 eqs. of Oxygen	"	1 Choleic Acid. 2 Cholic Acid. 12 Urea. 36 Carbonic Acid.

We regard it as a truth, which requires no special proof, that from albumen are derived gelatine and choleic acid as well as the fibrine of blood; and that, from gelatine and chondrine, uric acid and urea are derived.

The above formulæ express, according to the actual state of our knowledge, the proportions in which this *may* occur, not those in which it actually does occur. Herein consists the hypothetical parts of these formulæ; in this, namely, that we have no evidence of the actual occurrence of these transformations and resolutions of one body into others in the proportions here given. These have only probabilities in their favour.

But it appears with certainty from these formulæ, that albumen, with the addition of 10 eqs. of oxygen, contains precisely the elements of the substance of membranes and of choleic acid; that the fibrine of blood is perhaps albumen half-converted into gelatine; that gelatine, under the influence of the respiratory process, may be resolved exactly into uric acid or urea, carbonic acid and water; that when uric acid is formed from gelatine in the change of matter, the elements of choleic acid remain; and that the production of the constituents of urine must be very closely related to that of the constituents of the bile.

From these formulæ we may further conclude, that the nutritive value of the caseine of milk is greater for the child, and less for the adult than that of albumen; for it is certain that nature requires, and applies to certain purposes in the body of the young animal, the excess of the elements which caseine contains beyond those of albumen; and that these objects have no longer any importance on the adult animal. We may also conclude, from them, that the gelatinous substances taken in the food are not adapted to sanguification, while they increase the production of the constituents of the bile and of the urine, as has long been recognised by experience in regard to the latter.*

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* It is known that, by the action of oxidising agents on cholesterine, a peculiar acid, cholesteric acid, is obtained, (Redtenbacher): and that the same acid may be obtained in the same way from cholic and choleic acids, and from no other constituent or product found in the animal body. (Schlieper.) This establishes a con-

The gluten of grain, and the albumen of vegetable juices, are identical in composition with the albumen of blood. Vegetable caseine has also the composition of animal caseine.

The different kinds of grain are not alike in the amount of incombustible constituents or inorganic salts they contain. In wheat, the phosphoric acid varies from 40 to 48 (Th. Way and Ogston), even to 60 per cent. (Erdmann.)[*] There are varieties of wheat, the ashes of which are, in quantity and in the relative proportion of the salts, the same as those of boiled and lixiviated meat; and it cannot be maintained that bread, made of such flour, would, if the only food taken, support life permanently.[†]

The finest wheat-flour contains more starch than the coarser; the bran of wheat is proportionally richer in gluten.

Fine American flour is one of the varieties which is richest in gluten, and is, consequently, one of the most nutritious.

Rye and rye-bread contain a substance resembling

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nexion between the acids of the bile and the peculiar fat, which often occurs in such enormous quantity in that secretion. It is not impossible that cholesterine may be a product of the destruction of the acids of the bile in the vital process. Hitherto, no one knows what becomes of these acids.

[*] Ashes of wheat, analysed by Erdmann, after deducting peroxyde of iron (1·33 per cent.); silica and sand (3·37 per cent.)

Alkaline Phosphates, ($P O_5$, $2 M O$) . . .	49·18
Earthy phosphates, ($P O_5$, $2 M O$)	23·13
Free phosphoric acid	27·69
	100·00

Compare with this the excellent analysis of Th. Way and Ogston.

[†] Is the finest flour as perfect a food as the entire meal? I think not, and I beg here to recal the experiment of Magendie, in which a dog, exclusively fed with white wheaten bread, died after forty days; while another dog, fed on black bread (brown bread, made of the flour with the bran) lived on without any disturbance of his health. (Millon, Comptes Rendus, xxxviii. p. 40).

starch-gum (or dextrine, as it is called) in its properties, which is very easily converted into sugar. The starch of barley approaches in many properties to cellulose, and is, therefore, less digestible. Oats are particularly rich in plastic substances; Scotch oats richer than what is grown in England or in Germany. This kind of grain contains, in its ashes, after deduction of the silica of the husks, very nearly the same ingredients as are found in the ashes of the juice of flesh.

In order to promote the separation of the flour from the husks, the corn is, by many millers, slightly moistened before grinding. If this moisture be not thoroughly removed from the flour by very careful drying in an artificial heat, it causes the flour, when kept, to spoil; it acquires a musty flavour, cakes together in lumps, and feels harsh like gypsum. The dough made of this flour becomes greasy, and yields a heavy dense bread, not porous as it ought to be. This spoiling depends on an action of the gluten on the starch, which action is promoted by the moisture, and by which acetic and lactic acids are formed in the flour. These acids render the gluten soluble in water, which, naturally, it is not.

Many salts render the gluten again insoluble, apparently, by forming with it a chemical combination; and the bakers of Belgium discovered, about twenty years ago, how to bake from damaged flour, by adding sulphate of copper (a poison) to the dough, a bread in appearance and external properties as beautiful as from the best flour. This mode of improving its physical properties, of course deteriorates its chemical properties. Alum has the same effect as sulphate of copper. When added to the dough, it renders the bread very white, elastic, firm, and dry; and the London bakers, in consequence of the demand for white bread, such as the English and American flour, usually so good, yields, appear to have been compelled to add alum to all flour in the baking. I saw in an alum manufactory, in Scotland, little mounds of finely ground alum, which was destined for the use of the London bakers.

Since phosphoric acid forms with alumina a compound hardly decomposable by alkalies or acids, this may perhaps explain the indigestibility of the London bakers' bread, which strikes all foreigners. A small quantity of lime-water, added to the musty or damaged flour, has the same effect as the alum or sulphate of copper, without being followed by the same disadvantages.

The careful mixture with the saliva during the mastication of bread, is a condition essential to the rapid digestion of the starch. Hence the increase of digestibility obtained in bread by the porous form given to it.

This porosity and lightness is produced in the dough by a process of fermentation. Beer-yeast is added to the dough, which brings into fermentation the sugar formed by the action of the gluten on the starch; and the open porous texture of the mass is the result of the carbonic acid thus formed in every part of it.

In making rye-bread, *sour dough* is employed; there is added to the fresh dough of rye-meal, a portion of old dough in a state of fermentation, from a former baking, and by its action on the sugar there is always formed a certain amount of acetic and lactic acids, in consequence of which the bread has a slightly acid re-action.

Many chemists are of opinion that the flour, by the fermentation in the dough, loses somewhat of its nutritious constituents, from a decomposition of the gluten; and it has been proposed to render the dough porous without fermentation, by means of substances which, when brought into contact, yield carbonic acid. But on a closer investigation of the process, this view appears to have little foundation.

When flour is made into dough with water, and allowed to stand in a gentle warmth, a change takes place in the gluten of the dough, similar to that which occurs after the steeping of barley, in the commencement of germination in the seeds, in the preparation of malt; and in consequence of this change, the starch (the greater part of it in malting, in dough only a small per centage) is converted into sugar. A small portion of the gluten passes into the soluble state, in which it acquires the properties of albumen, but by this change it loses nothing whatever of its digestibility or of its nutritive value.

We cannot bring flour and water together without the formation of sugar from the starch, and it is this sugar, and not the gluten, of which a part enters into fermentation, and is resolved into alcohol and carbonic acid.

We know, that malt is not inferior in nutritive power to the barley from which it is derived, although the gluten contained in it has undergone a much more profound alteration than that of flour in the dough, and experience has taught us, that in distilleries where spirits are made from potatoes, the plastic constituents both of the potatoes and of the malt which is added, after having gone through the entire course of the processes of the formation and the fermentation of the sugar, have lost little or nothing of their nutritive value. It is certain, therefore, that in the making of bread there is no loss of gluten. Only a small part of the starch of the flour is consumed in the production of sugar, and the fermentative process is not only the simplest and best, but also the cheapest of all the methods which have been recommended for rendering bread porous. Besides, chemical preparations ought never, as a general rule, to be recommended by chemists for culinary purposes; since they hardly ever are found pure in ordinary commerce. For example, the commercial crude muriatic acid, which it is recommended to add to the dough along with bicarbonate of soda, is always most impure, and very often contains arsenic, so that the chemist never uses it, without a tedious process of purification for his purposes, which are of far less importance.

The plans which have hitherto been proposed, with the view of replacing the flour in making bread, so as to render it cheaper in times of scarcity and famine, only prove, how far we are still removed from a rational system of dietetics, founded on scientific principles. The price of food depends on the same causes, and is regulated by the same laws, as that of fuel. If we take the trouble to compare the prices of the various kinds of coal, or of firewood, or of browncoal (woodcoal), and turf or peat together, we shall find that the number of pence paid for a given weight or measure of these forms of fuel, is, as nearly as possible, in direct proportion to their true value, that is, to the number of degrees of heat which they give out in burning. In a district where beech, oak, and fir-wood are burned, it is a matter of indifference, in regard to price and heating power, which wood is chosen. Here the preference is given according to the object in view. For large, wide or long fire-places, fir-wood is the best, because its flame extends farthest; for small narrow fire-places beech-wood is preferred on account of the charcoal it yields. In estimating such values, one person may err, but the daily experience of many thousands neutralises the mistakes of individuals.

The average price of the various kinds of food in a large country is, as a general rule, the measure of their nutritive value; the variations in price in different places arise from local causes (ease or difficulty of transport, good or bad roads, rivers, canals, &c.). For the purposes of nutrition rye is not cheaper than wheat; rice and potatoes are not cheaper than grain.

Wheat flour cannot be replaced advantageously, as far as this quality is concerned by any other kind of flour. It is only in times of scarcity or famine, that these relations of value are somewhat modified. Potatoes and rice then reach a higher price than usual, because, in addition to their true nutritive value, they possess another, namely, their value as respiratory matter, which in times of plenty is not reckoned.

Potato starch, Dextrine (starch-gum), or the pressed pulp of turnips and beet-root, when added to flour, yield a mixture, the nutritive value of which is equal to that of the entire potato or lower still; but no one can consider the change of grain or flour into a food of equal value with potatoes or rice as an improvement. The true problem is to render potatoes or rice similar or equal to wheat in their effects, and not *vice versâ*. It is better, under all circumstances, to boil the potatoes and eat them along with bread, than to add potatoes or potato starch to flour before it is made into bread; which should be strictly prohibited by police regulations, on account of the cheating to which it would inevitably give rise. The addition of pease or bean meal, or of skim milk cheese to rye flour, as is done in Bavaria (Dr. Vogel), answers the purpose much better, but nothing is thereby gained in price.

The only real saving and profit in this way is that made by using such articles of refuse as are not used for food in the ordinary course of events.

In England~~, for example,~~ many thousand cwts. of the finest and best flour are used to yield starch for dressing cotton goods, and the gluten, which forms the refuse of this manufacture, amounting to from 12 to 20 per cent. of the dried flour, is, for the most part, lost as food for men. In the experiments of the French academicians dogs were fed for ninety days exclusively with the gluten of flour, which was devoured raw by the animals without any repugnance, and without interruption. No perceptible disturbance of their health occurred.*

With the exception of the organic substances in the juice of flesh, there is no substance which approaches more nearly to the fibrine of flesh, in its properties and nutritive value, than the gluten of wheat. When boiled with a little salt and water, dried, and ground to a coarse meal, gluten is easily preserved, and with the addition of some extract of meat and kitchen vegetables, it yields the strongest, best-flavoured, and most nutritious soup. As a provision for ships and fortresses, the dried gluten of wheat (along with extract of meat) would enable us to save a large quantity of meat.

In the brewing of beer, as is well known, a separation takes place between the sanguinigenous matters of the barley and the starch. Of the former, those portions which dissolve in the wort, and are separated as yeast during the fermentation, are lost for the purpose of nutrition. Only that portion which remains undissolved with the husks is used as fodder for cattle, and much prized, especially for milch cows. In making the infusion, or worts, there is deposited above the husks a dough-like mass, consisting of the finest suspended particles of the ground malt, and which is well known to German brewers under the name of *Obertaig* (upper dough). This upper dough contains as much as 26 per cent. of plastic matter, and from 4 to 8 per cent. of starch, and, when added to an equal weight of flour, the large amount of water contained in it being taken into account, yields an unexceptionable bread. The breweries of Würtemburg yield annually

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* Gluten, from a starch manufactory, yielded 1 to 1¼ per cent. of ashes, which contained 7·87 per cent. of potash, 2·14 of soda, 17·31 of lime, 12·08 of magnesia, 7·13 peroxide of iron, together 47·13 of bases, with 52·08 of phosphoric acid, 0·69 of sulphuric acid, and 0·09 of chlorine. (Kekulé.)

30,000 cwt. of this malt dough, which might furnish 17,000 cwt. of bread. (Schlossberger.) All these means of relieving the necessities of the poor in years of famine are only local, and amount to little in comparison with the consumption, for the inhabitants of a large country. There is only one permanent means of saving for the largest population, which is, that the wheat or rye, ground fine, should be used for baking bread, unbolted, that is, the flour along with the bran, and the whole of the nutriment existing in the grain thus rendered available for man.

In 1658, an ordinance of Louis XIV. prohibited, under heavy pecuniary penalties, the grinding of the bran a second time; which, according to the then existing arrangements of flour mills, must have caused a loss of 40 per cent. In the seventeenth century, Vauban estimated the annual consumption of a man at nearly 712 lbs. of wheat, a quantity which now suffices nearly for two men; and by the improvements in mills there are now gained to the population immense masses of nutritious matter, of the annual value of many millions, which were formerly used for animals alone; whereas for the feeding of animals the bran may be far more easily replaced by other food, not in the least adapted for the use of man. The very high value of bran as food has been long ago pointed out, especially by Millon. Wheat does not contain above 2 per cent. of indigestible woody fibre, and a perfect mill, in the most extended sense, should not yield more than that proportion of bran; but, practically, the best mills always yield, even now, from 12 to 20 per cent.: (10 per cent. coarse bran, 7 fine bran, 3 bran flour); and the ordinary mills produce as much as 25 per cent. of bran, containing 60 or 70 per cent. of the most nutritious constituents of the flour.

It is evident, that by baking bread with unbolted flour the mass of bread may be increased from one-sixth to one-fifth, and the price of it lowered by the difference between the price of the bran as fodder for cattle and that of the flour gained by not bolting the flour.* As an addition to the flour, in times of scarcity, the bran has even a much higher value, and cannot be replaced by any other nutritious matter.

The separation of the bran from the flour by bolting is a matter of luxury, and injurious rather than beneficial as regards the nutritive power of the bread. In ancient times, down to the period of the Emperors, no bolted flour was known. In many parts of Germany, especially in Westphalia, the entire meal, including the bran, is baked into the brown bread called Pumpernickel; and there is no country where the digestive organs of the population are in a better condition. The boundaries between the Lower Rhine and Westphalia may be traced by the very remarkable size of the remains of preceding meals left by passengers behind the hedges: and possibly it is from observing these distinguished evidences of the digestive capacity of the Westphalians that English physicians have been induced to recommend to the great in England brown bread made with unbolted flour, that is, with the entire flour; which bread, in many rich families, adorns the breakfast table.

Among all the arts known to man, there is none which enjoys a juster appreciation, and the products of which are more universally admired, than that

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* Composition of Wheat Bran.

	(Millon).	(Kekulé).
Starch	52·0	67.3
Gluten	14·9	
Sugar	1·0	
Fat	3·6	4·1
Woody Fibre	9·7	9·2
Salts	5·0	5·6
Water	13·8	13·8
	100·0	100·0

which is concerned in the preparation of our food. Led by an instinct, which has almost reached the dignity of conscious knowledge, as the unerring guide, and by the sense of taste, which protects the health, the experienced cook, with respect to the choice, the admixture, and the preparation of food, has made acquisitions surpassing all that chemical and physiological science have done in regard to the doctrine or theory of nutrition. In soup and meat sauces, he imitates the gastric juice; and by the cheese which closes the banquet, he assists the action of the dissolved epithelium of the stomach. The table, supplied with dishes, appears to the observer like a machine, the parts of which are harmoniously fitted together, and so arranged, that, when brought into action, a maximum of effect may be obtained by means of them. The able culinary artist accompanies the sanguigenous matter with those which promote the process of solution and sanguification, in due proportion; he avoids all kinds of unnecessary stimuli, such as do not act in restoring the equilibrium; and he provides the due nourishment for the child as well as the old man, as well as for both sexes.

The intelligent and experienced mother, or nurse, chooses food for the child with the same attention to the laws of nature; she gives him chiefly milk and farinaceous food, always adding fruits to the latter; she prefers the flesh of adult animals which is rich in bone earth, to that of young animals, and always accompanies it with garden vegetables; she gives the child especially bones to gnaw,* and excludes from its diet veal, fish, and potatoes; to the excitable child, of weak digestive powers, she gives, in its farinaceous food, infusion of malt, and uses milk-sugar, the respiratory matter prepared by nature her-

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* In Upper Hesse, near Giessen, the peasantry use, as an excellent domestic remedy in the teething of children, pure lime-water, which the little creatures eagerly take, a teaspoonful at a time.

self for its respiratory process,* in preference to cane-sugar; and she allows him the unlimited use of salt.

The unequal effects of different kinds of food, with regard to the bodily and mental functions of men, and the dependence of these on chemical and physiological causes, are indisputable; but as yet the attempt has hardly been made to explain these differences according to the rules of scientific research.

Many writers maintain that flesh and bread contain phosphorus, that milk and eggs contain a phosphorised fat like brain, and that the origin, and, consequently, the activity of the matter of the brain is connected with this phosphorised fat. Hence no excess of phosphorus can be supposed, for example, to exist in thinkers, (because they consume much phosphorus); and it is a certain truth that there is *no thought without phosphorus!* (See "Lehre der Nahrungsmittel für das Volk. von Dr. Jac. Moleschott. Erlangen." 1850, p. 116.) But no evidence is known to science, tending to prove that the food of man and animals contains phosphorus as such, in a form analogous to that in which sulphur occurs in it. It has long been proved that the cause of the amount of phosphoric acid obtained by the incineration of animal matters, or of food, being less than may be detected in the moist way, is merely the loss of a certain portion of the phosphoric acid, caused by its decomposition and volatilisation, in consequence of the combined action of heat and charcoal; and that this loss may be entirely prevented by the addition of alkalies or alkaline earths, which combine with and retain the free phosphoric acid. No one has ever yet detected phosphorus in any fat of the body, of the brain, or of the food, in any other form than that of *phosphoric acid*. The notion that such other

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* In the cheese dairies of England thousands of cwts. of this valuable respiratory matter are annually lost in the whey.

compounds of phosphorus exist in the body, and that their presence is connected with the production of thoughts in the human brain, proceeds generally from amateurs in science, and rests on superficial observations, without the slightest scientific foundation.

It is certain that three men, one of whom has had a full meal of beef and bread, the second cheese or salf fish, and the third potatoes, regard a difficulty which presents itself from entirely different points of view. The effect of the different articles of food on the brain and nervous system is different, according to certain constituents peculiar to each of these forms of food.

A bear, kept in the anatomical department of this university, exhibited a very gentle character as long as he was fed exclusively on bread. A few days of feeding with flesh rendered him savage, prone to bite, and even dangerous to his keeper. It is well known that the *vis irascibilis* of swine may be so exalted by feeding them with flesh, that they attack men.

The carnivora are, in general, stronger, bolder, and more pugnacious, than the herbivorous animals on which they prey; in like manner, those nations, which live on vegetable food, differ in disposition from such as live chiefly on flesh.

If the strength of individuals consist of the sum of the effects of force which they can exert, without injury to health, in order to overcome resistance, this obviously has a direct ratio to the plastic matters in their food. Those nations which feed on wheat and rye are, in this sense, stronger than those whose food is potatoes and rice; and these again are stronger than the negroes, who feed on couscous, manioc, cassava, or taro.

The relations of the respiratory matters in food are different. These are chiefly distinguished by the rapidity and the permanence of their effects.

Hours must elapse before all the starch of bread, in the stomach and intestines, has become soluble, so as to enter the blood and be employed in the respiratory process. Milk-sugar and grape-sugar require no preparation by the digestive organs, and thus enter the blood more rapidly. The effect of fat is the slowest in being produced, but it lasts much longer. Of all respiratory matters, alcohol acts most rapidly. Wine, and fermented vegetable juices in general, differ from spirits in containing alkalies, organic acids, and certain other substances, which it is the business of chemistry more especially to ascertain. Beer is an imitation of wine. Brandy (whisky, rum,) consists of water and one of the ingredients of wine.

In consequence of the presence of its characteristic ingredients, wine unites in its composition a number of conditions, by the composition of which, in the human body, the consequences of the action of alcohol in the nervous system, which exalts the functions of the brain and spinal chord, are, after a certain time, more or less completely neutralised.

The commercial value of wine is directly proportional to its immediate effects, and inversely proportional to its disagreeable after-effects (called, in Germany, *Katsenjammer*). Other things being the same, its price is higher the more perfectly its effects are rendered harmless by a corresponding increase in the secretions of the lungs and of the kidneys. The alcohol is always considered in fixing the prices, but in the nobler wines, the price bears no fixed ratio to the amount of alcohol, but is rather in proportion to that of the fixed ingredients.*

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* Arranged according to price, the following Rhenish wines contain :—

		of Alcohol.	of solid residue.	
Steinberger	1846	10·17	10.55	Fresenuis.
Marcobrunner	„	11·14	5.18	
Hattenheimer	„	10·71	4·21	
Steinberger	1822	10.87	9·94	Greiger.
Rüdesheimer	„	12·61	5·39	
Marcobrunner	„	11·6	5·10	
Geisenhermer	„	12·6	3·06	

The flavour or bouquet of wine has only in so far an influence on its price as it is an index to all its effects taken together.

As a restorative, a means of refreshment, where the powers of life are exhausted, of giving animation and energy where man has to struggle with days of sorrow, as a means of correction and compensation when misproportion occurs in nutrition, and the organism is deranged in its operations, and as a means of protection against transient organic disturbances, wine is surpassed by no product of nature or of art.

The nobler wines of the Rhine and many of those of Bordeaux, are distinguished above all others by producing a minimum of injurious after effect. The quantity of wine consumed on the Rhine by persons of all ages, without perceptible injury to their mental and bodily health, is hardly credible. Gout and calculous diseases are nowhere more rare than in the district of the Rheingau, so highly favoured by nature. In no part of Germany do the apothecaries' establishments bring so low a price as in the rich cities on the Rhine; for there wine is the universal medicine for the healthy as well as the sick, it is considered as milk for the aged (see Appendix).

Alcohol stands high as a respiratory material. Its use enables us to dispense with the starch and sugar in our food, and is irreconcileable with that of fat.*

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* Persons accustomed to the use of wine, when they take cod-liver oil, soon lose the taste and inclination for wine.

Since the establishment of Temperance or Abstinence Societies, it was thought fair, in many English families, to compensate in money those servants who took the pledge and no longer drank beer, for the former daily allowance of beer; but it was soon found that the monthly consumption of bread increased in a striking degree, so that the beer was twice paid for; once in money, and a second time in its equivalent of bread.

On the occasion of the meeting of the Peace Congress in Frankfort the proprietor of the celebrated Hôtel de Russie told me, with

In many places destitution and misery have been ascribed to the increasing use of spirits. This is an error.

The use of spirits is not the cause, but an effect of poverty. It is an exception from the rule when a well-fed man becomes a spirit-drinker. On the other hand, when the labourer earns by his work less than is required to provide the amount of food which is indispensable in order to restore fully his working power, an unyielding, inexorable law or necessity compels him to have recourse to spirits. He must work, but in consequence of insufficient food, a certain portion of his working power is daily wanting. Spirits, by their action on the nerves, enable him to make up the deficient power *at the expense of his body,* to consume to day that quantity which ought naturally to have been employed a day later. He draws, so to speak, a bill on his health, which must be always renewed, because, for want of means, he cannot take it up; he consumes his capital instead of his interest; and the result is the inevitable bankruptcy of his body.

Tea, coffee, and chocolate differ from wine in their action on the vital processes.

If we consider that in Europe and America more

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expressions of astonishment, that at his table at that time, a regular deficiency occurred in certain dishes, especially farinaceous dishes, puddings, &c.; an unheard of occurrence in a house in which the amount and proportion of the dishes for a given number of persons has been for years fixed and known. This dining-hall was filled with friends of peace, all of whom belonged to temperance unions, and drank no wine. Herr Sarg observed, that those who take no wine always eat more in proportion. In wine countries, therefore, the price of the wine is always included in that of the dinner, and it is considered just that in hotels people should pay for wine, even when they drink none.

"O monstrous! but one halfpenny worth of bread to this intolerable deal of sack!"—*Shakspeare.*

than eighty million pounds of tea, and in the Customs Union more than sixty million pounds of coffee are annually consumed; that in England and America tea forms part of the daily arrangements of the poorest labourer, as well as of the richest landowner; that in Germany the people in the country and in towns adhere the more tenaciously to coffee, the more the abundance and choice of food is limited by their poverty; and that the lowest wages have always a column in the book for coffee and another for bread and potatoes:—when we reflect on these facts it is impossible to admit the assertion, "that the use of coffee and tea is a matter of mere habit." (Knapp, Die Nahrungsmittel. Brunswick, 1847).

It is true that thousands have lived without a knowledge of tea or coffee, and daily experience teaches that under certain circumstances they may be dispensed with without disadvantage to the merely animal vital functions. But it is an error, certainly, to conclude from this that they may be altogether dispensed with in reference to their effects; and it is a question whether, if we had no tea and no coffee, the popular instinct would not seek for and discover the means of replacing them. Science, which accuses us of so much in these respects, will have in the first place to ascertain whether it depend on sensual and sinful inclinations merely, that every people of the globe has appropriated some such means of acting on the nervous life; from the shore of the Pacific, where the Indian retires from life for days in order to enjoy the bliss of intoxication with koka, to the Arctic regions, where Kamtschatdales and Koriakes prepare an intoxicating beverage from a poisonous mushroom.

We think it, on the contrary, highly probable, not to say certain, that the instinct of man, feeling certain blanks, certain wants of the intensified life of our times, which cannot be satisfied or filled up by mere quantity, has discovered, in these products of vegetable life, the true means of giving to his food the desired and necessary quality.

Every substance, in so far as it has a share in the vital processes, acts in a certain way on our own nervous system, on the sensual appetites and the will of man.

Macaulay, the distinguished enquirer in the province of history, has indeed, in his classical work, bestowed a well merited attention on the influence of coffee-houses on the political condition of England in the seventeenth century, but the share which the constituents of coffee then had in determining the direction of mental activity is a problem which has yet to be solved.

What we know of the physiological effects of these drinks is not worth mentioning. These effects are usually ascribed to the presence of theine (identical with the caffeine in coffee, and found also in Maté or Paraguay tea), and this is probably correct. There are no drinks, which in their complexity and in the nature of certain constituents, have more resemblance with soup than tea and coffee, and it is very probable that the use of them as a part of food depends on the exciting and vivifying action which they have in common with soup.

When common tea leaves are placed on a watch-glass, loosely covered with paper and heated on a hot iron plate gradually to the point at which browning takes place, long white shining crystals appear on the paper and on the surface of the leaves. This is theine.

By its properties theine belongs to the class of the organic bases, all of which, without exception, have an action on the nervous system. If arranged in a series, beginning with theine, the bodies at the end of the scale, strychnine and brucine, act as the most frightful poisons; quinine, standing near the middle, is a highly-prized remedy; the constituents of opium have, in certain doses, medicinal effects, in larger doses they are poisonous. The medicinal and poisonous organic bases contain, for one equivalent of nitrogen, more than eight equivalents of carbon. Theine or caffeine, and the bodies resembling them, which may be taken without injury, all, on the other hand, contain, for the same amount of nitrogen, less carbon than the constituents of blood (8 eqs.)

Theine is related, in composition, to no organic nitrogenous base more closely than to kreatinine, that remarkable compound, produced in the vital process, and occurring in the muscular system of animals; and to glycocoll, which we may suppose to exist in gelatine coupled with another compound as may be seen the following formulæ:—

Theine	$C_8 N_2 H_5 O_2$
Kreatinine	$C_8 N_3 H_7 O_2$
Glycocoll (anhydrous). . . .	$C_8 N_2 H_8 O_6$
Kreatine	$C_8 N_3 H_{11} O_6$
Theobromine (in Cacao) . . .	$C_7 N_2 H_4 O_2$

We see, by these formulæ, that kreatinine contains the elements of theine and those of amide (NH_2), and that glycocoll and kreatine differ in this, that the latter contains 1 eq. of ammonia more than the former.

Theine yields, in certain processes of decomposition, a series of most remarkable products, which have much analogy with those derived from uric acid in similar circumstances. (Rochleder.) The infusion of tea differs from that of coffee by containing iron and manganese. If we evaporate to dryness a clear infusion of Pekoe or Souchong tea, and incinerate the residue perfectly, there is left an ash, which is often green from manganate of potash, and gives off chlorine when treated with hydrochloric acid in consequence of the presence of manganic acid. The presence of these metals in tea is the more remarkable, because the most delicate tests do not detect the iron in tea; if a salt of iron be added, the tea becomes black, like ink, on account of the presence of tannic acid. Infusion of tea contains a compound of iron, on which tannine obviously has no action.

We have, therefore, in tea (of many kinds) a beverage which contains the active constituents of the most powerful mineral springs, and however small the amount of iron may be, which we daily take in this form, it cannot be destitute of influence on the vital processes.*

By the presence of empyreumatic substances,

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* An infusion of 70 grammes of Pekoe tea contained 0·104 grammes of peroxyde of iron, and 0·20 grammes of protoxide of manganese. (Fleitmaun.)

Constituents of the Ashes of

	Infusion of tea.	Decoction of Coffee.	Cacao Beans.
	Souchong.	Java Coffee.	Guayaquil Cacao.
	(Lehmann)	(Lehmann)	(Zedeler)
Potash . .	47·45	51·45	37·14
Lime . . .	1·24	3·58	2·88
Magnesia . .	6·84	8·67	15·97
Peroxide of iron .	3·29	0·25	0·10
Phosphoric acid .	9·88	10·02	39·65
Sulphuric acid .	8·72	4·01	1·53
Silicic acid . .	2·31	0·73	0·17
Carbonic acid .	10·09	20·50	,,
Oxide of manganese	0·71	0·00	,,
Chloride of sodium	3·62	K Cl 1·98	Cl 1·66
Soda . . .	5·03	,,	,,
Charcoal and Sand	1·09	0·49	,,
	100·77	100·68	100·33

100 parts of the leaves (Souchong) extracted by boiling water give 15·536 parts of dried extract, which yield 3·06 of ashes (=19·69 per cent. of the extract); 100 parts of roasted coffee yielded by decoction with water, 21·52 parts of extract, which gave 3·41 of ashes, (=16·6 per cent. of the extract); the cacao beans were shelled, and gave 3·62 per cent. of ashes.

roasted coffee acquires the property of checking those processes of solution and decomposition which are begun and kept up by ferments. We know that all empyreumatic bodies oppose fermentation and putrefaction; and that, for example, smoked flesh is less digestible than that which is merely salted. Persons of weak or sensitive organs, will perceive, if they attend to it, that a cup of strong coffee after dinner instantly checks digestion. It is only when the absorption and removal of it has been effected, that relief is felt. For strong digestions, which are not sufficiently delicate reagents to detect such effects, coffee after eating, serves, from the same cause, to moderate the activity of the stomach, exalted beyond a certain limit by wine and spices. Tea has not the same power of checking digestion; on the contrary, it increases the peristaltic motions of the intestines; and this is sometimes shown in producing nausea, especially when strong tea is taken by a fasting person.

It has already been mentioned, that the daily consumption of respiratory matter amounts to five or six times the weight of the plastic matter, and in years of scarcity the want of the former is first and most sensibly felt by all classes of the people. While the prices of fat and butter rise with that of grain, and potatoes become even proportionally dearer than grain, the price of meat generally remains the same as in cheaper years. One reason of this is, that bread may be substituted for meat, but for the wants of man cannot be so perfectly replaced by meat.* Another

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* In describing his residence in the Pampas, Darwin says, in his admirable work, which contains a rich store of the finest observations; "We were able here (Tapalguen, 17th September) to buy some biscuit. I had for some days eaten only meat, and felt quite well on this diet, but I observed that it was adapted only to a very active mode of life. I have heard that sick persons in England, put on animal diet alone, could not endure it, even with the hope

cause of the comparatively low price of meat depends on the circumstance, that in years of bad harvests, from an excess of moisture, should the ordinary nutritious plants fail, there is abundance of green fodder, of clover, grass, and turnips. Meat retains its lower price, because the demand for it does not increase like that for bread. In dry years the farmer has no fodder, he is forced to kill his cattle and sell them for what they will fetch, and the overstocking of the market renders meat even cheaper than in ordinary years.

Man, when confined to animal food, requires for his support and nourishment extensive sources of food, even more widely extended than the lion and tiger, because, when he has the opportunity, he kills without eating.

A nation of hunters, on a limited space, is utterly incapable of increasing its number beyond a certain point, which is soon attained. The carbon necessary for respiration must be obtained from the animals, of which only a limited number can live on the space supposed. These animals collect from plants the constituents of their organs and of their blood, and yield them, in turn, to the savages who live by the chase alone. They, again, receive this food unaccompanied by those compounds, destitute of nitrogen, which, during the life of the animals, served to support the respiratory process.

While the savage with one animal and an equal weight of starch could maintain life and health for a certain number of days, he would be compelled, if

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of health before their eyes; and yet the Gauchos in the Pampas, during many months, eat nothing but beef. But I must observe, that they eat a very large quantity of fat, and they despise dry, lean flesh, like that of the Agouti." (Darwin's Travels).

Homer omits no opportunity in describing the meals and feasts of his heroes, of singing the praise due to the "blooming" fat of the swine's back.

confined to flesh alone, in order to procure the carbon necessary for respiration, during the same time, to consume five such animals. His food contains an excess of plastic matter; during the greater part of the year, that which is wanting is the respiratory material which ought to accompany the sanguinigenous food. Hence the tendency to brandy-drinking, always observed in men who live on flesh exclusively.

The practical view of agriculture cannot be more clearly or profoundly conceived than it was by the North American chief, whose speech on the subject is reported by Crèvecœur. The chief, in recommending agriculture to his tribe, the Mississean Indians, said: "Do you not see that the whites live on corn, but we on flesh? that the flesh requires more than thirty moons to grow, and is often scarce? that every one of the wonderful seeds, which they scatter on the soil, returns them more than an hundred-fold? that the flesh has four legs to run away, and we only two to catch it? that the seeds remain and grow, where the white man sows them? that winter, which for us is the season of laborious hunts, is to them a time of rest? It is for these reasons that they have so many children, and live longer than we do. I say, then, to every one who hears me, before the trees above our huts shall have died of age, before the maples of the valley cease to yield us sugar, the race of the sowers of corn will have extirpated the race of flesh-eaters, unless the hunters resolve also to sow."

In his difficult and laborious life of the chase, the Indian consumes in his limbs a large sum of force, but the effect produced is very trifling, and bears no proportion to the expense.

Cultivation is the economy of force. Science teaches us the simplest means of obtaining the *greatest* effect with the *smallest* expenditure of power, and with given means to produce a maximum of force. The unprofitable exertion of power, the waste of force in agriculture, in other branches of industry, in science, or in social economy, is characteristic of the savage state, or of the want of true civilisation.

Herein consists, in fact, the extraordinary superiority of power, which distinguishes our period from all earlier times; in this, namely, that the development of the natural sciences and of mechanics, and the study of all the causes which produce mechanical motion and change of place, have led to the more accurate acquaintance with the laws which enable men to convert into willing and obedient servants those natural forces which formerly excited fear and terror.

Like a Prometheus, man, with the aid of the divine spark from above, which, when fed by religion and morality, is the foundation of all mental improvement, has infused life into the elements of the globe.

The steam-engine receives food and drink, and breathes like an animal; in its body there exists a source of heat and a source of power, by means of which internal and external effects of motion are produced; the most perfectly trained horse does not more patiently obey man's will, than the locomotive of our railways, which goes fast or slow, stands still and obeys the lightest touch of his fingers.

Science, which causes machinery to do the work formerly done by slaves, has established a more just proportion between the forces of external nature and the organic force.*

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* The chaste queen of Ithaca, in the absence of her lord, Ulysses, required, as Homer tells us, twelve female slaves, who laboured day and night, to grind the corn necessary for the support of her household. It was a simple family economy, and I exaggerate in assuming that Penelope had to feed, daily, three hundred people. In these circumstances, therefore, where all labour was performed in the sweat of man's brow, one person was required to grind corn for twenty-five, perhaps for only half that number. In our days the grinding of corn employs far fewer hands. In the mill at St. Maur, near Paris, the grain for a hundred thousand soldiers can be ground every day by twenty workmen; that is, one

The sum of the rays of light and heat, which the earth receives from the sun, is a fixed value, but it is distributed on the earth's surface, in consequence of causes which must be named providential, unequally. Hence, there is at one place an excess, which increases the production of the conditions essential to life; at another there is a deficiency, which causes that production to fall off. If the channels exist, through which these forces may flow both ways, an equilibrium is spontaneously effected; there is nowhere excess, and nowhere deficiency.

In like manner, riches and its shadow, poverty, are distributed over the earth. At all times the relative proportion of them has been the same and unchangeable. Any permanent increase in wealth is opposed by circumstances, which set a limit to it. As the blood moves from the great arterial trunks towards the capillaries, the largest income is consumed, and flows through an infinite number of smaller channels back to the original source.

Where the light is strong the shadows appear darker; but nature wills, that in all degrees of light, vigorous plants shall grow. Without trees there would be no underwood, no corn, and no crops, for trees attract the fertilising rain, and cause the springs perpetually to flow, which diffuse prosperity and comfort. The theories of modern socialism would have no shadow anywhere; but if the last blade of grass which casts a shadow were destroyed, then there would indeed be light everywhere, but with it universal death, as in the desert of Sahara.

By means of the forces produced in his frame, man

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labourer for five thousand consumers. Penelope could only *give*, doubtless, a very meagre pay to her twelve slaves, although overwhelmed with labour, because the produce of that labour was relatively so small. (Chevallier. Lettres sur l'Organisation *du* Travail, Paris. Capelle, 1848, p. 29.)

opposes to the natural forces which strive incessantly to annihilate his existence, a resistance, which must be daily renewed, if his continuance for a season is to be secured.

In every hour a portion of our body dies off, and even in the state of perfect health, the machine, after seventy or eighty years, becomes the prey of the inorganic powers ; all resistance ceases ; the elements of the machine return to the atmosphere and to the soil.

Life is a continual struggle with the forces of Nature, a constant alternate disturbance and restoration of a state of equilibrium.

Man requires, in the form of food and drink, the means of producing force and heat ; he thus creates in his body the resistance which he must oppose to the action of the atmosphere, which daily takes up a part of his organism.

In order to preserve his temperature, and to protect him against the weather, he requires a *dwelling, clothing, and fire ;* in order to preserve health, he must have the means of insuring *personal cleanliness*, and to restore it, he must have *medicine*.

Food and drink can, to a certain extent, represent and replace clothing, fire, and medicine ; but they themselves are not replaceable by the supply of any of the other wants of life—they are absolute or indispensable necessaries.

When there is a want of internal resistance, as in starvation, the same natural forces, which determine the vital phenomena, act like a sword, which gradually but irresistibly penetrates to the central point of life, and puts an end to its activity.

Man requires, for the development, perfection, and preservation of the peculiar actions of his organs of sense, certain other conditions, the necessity for which leads him to pursue *the agreeable* and *the profitable*.

Besides these, man has still a number of other wants, arising from his intellectual nature, which are not satisfied by means of natural forces. Such are the manifold conditions of the intellectual functions, on the development, perfection, and preservation of which depend the due and judicious application of his bodily powers, as well as the bending and employment of the natural forces to satisfy all his wants, whether those which are essential to life, or those which are profitable and agreeable only.

As in the body of an individual, so also in the sum of all individuals, which constitutes the state, there goes on a change of matter, which is a consumption of all the conditions of individual and social life.

Silver and gold have to perform in the organism of the state the same function as the blood corpuscles in the human organism. As these round discs, without themselves taking an immediate share in the nutritive process, are the medium, the essential condition of the change of matter, of the production of the heat and of the force by which the temperature of the body is kept up, and the motions of the blood and all the juices are determined, so has gold become the medium of all activity in the life of the state.

During the Middle Ages, the tax-payer paid his imposts in corn, wine, eggs, and fowls, and in feudal services and labour; all the necessaries of life he produced for himself. Colonial wares were unknown to him, and, with half a pound of copper coin, he procured the tools he required. The municipal communities had their common breweries, and in many places the authorities sold wine, and drew it for the citizens. Gold and silver were, for the great majority, goods which they wore ostentatiously on their clothes or furniture. But since gold has assumed, in the organism of the state, a function corresponding to the conveyance of oxygen in the body, the rich use, in place of the massive vessels of silver and gold formerly so common, copper or white brass, plated with silver and gold.

The change of matter, in the state, as in the body, is the source of all its powers ; its continued existence depends on the restoration of the wasted materials, on the renovation or restoration of all the conditions of individual or social life. As in the animal body the change of matter may be measured by the number of blood corpuscles, which in a given time pass from the heart to the capillaries and from those back to the heart, so may the change of matter in the state be measured by the rapidity with which money passes from hand to hand. All causes which impede this motion, or which act on the change of matter, on waste and supply, as the natural forces do in the body, disturb the equilibrium, and produce peculiar conditions analogous to the diseases of the individual.

Compared with the effects produced by the rapidity of the circulation of money, its absolute quantity is almost nothing. The body of the state, in perfect health, is like the human body, through the heart and capillaries of which, in twenty-four hours, from 31,000 to 38,000 lbs. of blood pass, while the absolute amount of the blood is a thousand times smaller.

The sum of all the resistances, opposed by Nature to the continuance of life and to the acquisition of the conditions of life (which, with regard to the peculiar function of money, is equivalent to the acquisition of money,) is precisely so great, that the active power producible in man can come into equilibrium with it. Man, according to the laws of Nature, cannot, without endangering his continued existence, consume any part of his force in overcoming resistances, by overcoming which, he does not obtain the means of restoring his wasted powers.

A relation perfectly analogous exists in the organism of the state. Every waste of power, which does not serve for the reproduction of a condition essential to the life of the state, or the non-employment of power, which exists and may be employed to produce a condition of vitality, disturbs the health of the political body.

Just as every muscular fibre, every nerve, every part of a tissue in the animal body, has a share in the change of matter going on in it, and contributes its part to the preservation and continuance of the general processes of digestion, sanguification, motion of the juices, and secretion, as well as of all the actions of the limbs, the senses, and the brain, so must every individual in the state, according to the measure of the available force in his limbs, senses, or mind, contribute his share to the preservation and restoration of the vital phenomena in the general body. The effect of these forces is what we call *labour*.

Every part of the organism has a right to the freest use of its power of labour; and all have a right to labour, unimpeded and unchecked by others. The maximum of effect from the powers of labour, is inversely proportional to the sum of the resistances to be overcome; the greater the resistance, the less is the effect. The duty of a Christian state is to diminish, not to increase, the resistance or the obstacles which exist; but the doctrines of those excellent and sagacious men who brought conviction to the mind of the greatest statesman of our time—of that wise and large-hearted man, whose loss the nation to whom he belonged and the world will mourn for a century to come—appear, up to this time, to have found a congenial and fertile soil neither in the understanding nor in the hearts of men. It is ignorance of the conditions which determine the health, the prosperity, and the power of the State, which has caused the misproportions which in many states are the source of so many evils. Instead of a harmonious whole, we have an abortion,—a huge head on a dwarfish body; enormous arms, and thin, feeble legs; a large stomach, and small lungs. When accident and caprice, instead of foresight and reflection, or old customs, at war with the laws of nature, are allowed to regulate the motions and the expenditure of power in the organism of the State, the natural results are feebleness and defects, and, in their train, poverty and misery. Thus a barbarous state, by means of unjust and unequally distributed imposts, urges whole masses of the population, during their entire life, towards famine; compelling them to expend too great a sum of their own force, merely to prolong their existence, and for other objects, by which the powers of all the individual parts are not perfectly restored. Thus states with great standing armies have only the appearance of strength, because a perpetual phlebotomy abstracts the best part of their blood, and their noblest juices. Their strength is like that which the savage finds in the intoxication of brandy: when the intoxication has passed away, the power has fled with it.

"All those things which appear to be left to the free-will, the passions, or the degree of intelligence of men, are regulated by laws as fixed, immutable, and eternal as those which govern the phenomena of the natural world. No one knows the day or the hour of his own death; and nothing appears more entirely accidental than the birth of a boy or of a girl in any given case. But how many, out of a million of men living together in one country, shall have died in ten, twenty, forty, or sixty years,—how many boys and girls shall be born in a million of births,—all this is as certain, nay, much more certain, than any human truth."

"The statistics of courts of justice have disclosed to us the regular repetition of the same crimes, and have established the fact,—incomprehensible to our understandings, because we do not know the connecting links,—that in every large country, the number of offences, and of each kind of offence, may be predicted for every coming year with the same certainty as the number of the births and of the natural deaths. Of every 100 persons, accused before the supreme tribunal in France, 61 are condemned; in England, 71. The variations, on an average, amount hardly to the $\frac{1}{100}$ part of the whole. We can predict, with confidence, for fifteen years to come, the number of suicides generally,—that of the cases of suicide by fire-arms, and that of the cases of suicide by hanging.

"Every large number of phenomena of the same kind, which rise and fall periodically, leads to a fixed proportion. This is the law of large numbers, to which all things and all events, without exception, are subject. These laws have nothing to do with the essence of vice and virtue in the moral world, but with the external causes, and the effects they produce in human society. No one denies the influence of education, and of habits of order and labour on the conduct of men, but no one thinks of regarding this moral conduct as a mere result of those habits. Good education, and improved cultivation, diminish the number of offences, as well as that of the annual deaths in our tables of mortality."*

It is plain, that a knowledge of the true means of bringing human society nearer to a better condition, and of giving a permanent foundation to the happiness of nations, can only be attained by studying the influence of all other arrangements, customs, habits, and institutions, on the morality of mankind, according to the numerical method. This constitutes true natural science.

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* Quetelet "On Man and the Development of his Powers." German translation by Riecke. Stuttgard, 1838.

LETTER XXX.

Every one knows that in the immense, yet limited expanse of the ocean, whole worlds of plants and animals are mutually dependent upon, and successive to each other. The animals obtain their constituent elements from the plants, and restore them to the water in their original form, when they again serve as nourishment to a new generation of plants.

The oxygen which marine animals withdraw in their respiration from the air, dissolved in sea water, is returned to the water by the vital processes of sea plants; that air is richer in oxygen than atmospheric air, containing 32 to 33 per cent., while the latter contains only 21 per cent. This oxygen now combines with the products of the putrefaction of dead animal bodies, changes their carbon into carbonic acid, their hydrogen into water, while their nitrogen assumes again the form of ammonia.

Thus we observe that in the ocean a circulation takes place without the addition or subtraction of any element, unlimited in duration, although limited in extent, inasmuch as in a confined space the nourishment of plants exists in a limited quantity.

We well know that marine plants cannot derive a supply of *humus* for their nourishment through their roots. Look at the great sea-tang, the *Fucus giganteus:* this plant, according to Cook, reaches a height of 360 feet, and a single specimen, with its immense ramifications, nourishes thousands of marine animals, yet its root is a small body, no larger than the fist. What nourishment can this draw from a naked rock, upon the surface of which there is no perceptible change? It is quite obvious that these plants require only a hold,—a fastening to prevent a change of place,—as a counterpoise to their specific gravity, which is less than that of the medium in which they float. That medium provides the necessary nourishment, and presents it to the surface of every part of the plant. Sea-water contains not only carbonic acid and ammonia, but the alkaline and earthy phosphates and carbonates required by these plants for their growth, and which we always find as constant constituents of their ashes.

All experience demonstrates that the conditions of the existence of marine plants are the same which are essential to terrestrial plants. But the latter do not live like sea-plants, in a medium which contains all their elements and surrounds with appropriate nourishment every part of their organs: on the contrary, they require two media, of which one, namely the soil, contains those essential elements which are absent from the medium surrounding them, *i. e.* the atmosphere.

Is it possible that we could ever be in doubt respecting the office which the soil and its component parts subserve in the existence and growth of vegetables?—that there should have been a time when the mineral elements of plants were not regarded as absolutely essential to their vitality? Has not the same circulation been observed on the surface of the earth which we have just contemplated in the ocean,—the same incessant change, disturbance, and restoration of equilibrium?

Experience in agriculture shows that the production of vegetables on a given surface increases with the supply of certain matters, originally part of the soil which had been taken up from it by plants—the excrements of man and animals. These are nothing more than matters derived from vegetable food, which in the vital processes of animals, or after their death, assume again the form under which they originally existed, as parts of the soil. Now, we know that the atmosphere contains none of these substances, and therefore can replace none; and we know that their removal from a soil destroys its fertility, which may be restored and increased by a new supply.

Is it possible, after so many decisive investigations into the origin of the elements of animals and vegetables, the use of the alkalies, of lime and the phosphates, that any doubt can exist as to the principles upon which a rational agriculture depends? Can the art of agriculture be based upon anything but the restitution of a disturbed equilibrium? Can it be imagined that any country, however rich and fertile, with a flourishing commerce, which for centuries exports its produce in the shape of grain and cattle, will maintain its fertility, if the same commerce does not restore, in some form of manure, those elements which have been removed from the soil, and which cannot be replaced by the atmosphere? Must not the same fate await every such country which has actually befallen the once prolific soil of Virginia, now in many parts no longer able to grow its former staple productions—wheat and tobacco?

In the large towns of England the produce both of English and foreign agriculture is largely consumed; elements of the soil indispensable to plants do not return to the fields,—contrivances resulting from the manners and customs of English people, and peculiar to them, render it difficult, perhaps impossible, to collect the enormous quantity of the phosphates which are daily, as solid and liquid excrements, carried into the rivers. These phosphates, although present in the soil in the smallest quantity, are its most important mineral constituents. It was observed that many English fields exhausted in that manner immediately doubled their produce, as if by a miracle, when dressed with bone earth imported from the Continent. But if the export of bones from Germany is continued to the extent it has now reached, our soil must be gradually exhausted, and the extent of our loss may be estimated, by considering that one pound of bones contains as much phosphoric acid as a hundred-weight of grain.

The imperfect knowledge of Nature and of the properties and relations of matter possessed by the alchemists gave rise, in their time, to an opinion that metals as well as plants could be produced from a *seed*. The regular forms and ramifications seen in crystals, they imagined to be the leaves and branches of metallic plants ; and as they saw the seed of plants grow, producing root, stem and leaves, and again blossoms, fruit and seeds, apparently without receiving any supply of appropriate material, they deemed it worthy of zealous inquiry to discover the *seed* of gold, and the earth necessary for its development. If the seeds of metals were once obtained, might they not entertain hopes of their growth ?

Such ideas could only be entertained when nothing was known of the atmosphere, and its participation with the earth, in administering to the vital processes of plants and animals. Modern chemistry indeed produces the elements of water, and, combining them, forms water anew ; but it does not *create* those elements—it derives them from water ; the new formed artificial water has been water before.

Many of our farmers are like the alchemists of old, they are searching for the miraculous seed —the means, which, without any further supply of nourishment to a soil scarcely rich enough to support the natural sprinkling of indigenous plants, shall produce crops of grain a hundred-fold.

The experience of centuries, nay, of thousands of years, is insufficient to guard men against these fallacies ; our only security from these and similar absurdities must be derived from a correct knowledge of scientific principles.

In the first period of natural philosophy, organic life was supposed to be derived from water only; afterwards, it was admitted that certain elements derived from the air must be superadded to the water; but we *now* know that other elements must be supplied by the earth, if plants are to thrive and multiply.

The amount of materials contained in the atmosphere, suited to the nourishment of plants, is limited; but it must be abundantly sufficient to cover the whole surface of the earth with a rich vegetation. Under the tropics, and in those parts of our globe where the most general conditions of fertility exist,—a suitable soil, a moist atmosphere, and a high temperature,—vegetation is scarcely limited by space; and, where the soil is wanting, the decaying trees, their bark and branches, become themselves the seat of vegetation and a soil for other plants. It is obvious there is no deficiency of atmospheric nourishment for plants in those regions, nor are these wanting in our own cultivated fields: all that plants require for their development is conveyed to them by the incessant motions of the atmosphere. The air between the tropics contains no more than that of the arctic zones; and yet how different appears the amount of produce of an equal surface of land in the two situations!

This is easily explicable. All the plants of tropical climates, the oil and wax palms, the sugar-cane, &c., contain only a small quantity of the sanguinigenous bodies necessary to the nutrition of animals, as compared with our cultivated plants. The tubers of the potato in Chili, its native country, where the plant resembles a shrub, if collected from an acre of land, would scarcely suffice to maintain an Irish family for a single day (Darwin). The result of cultivation in those plants which serve as food, is to produce in them those constituents of the blood. In the absence of the elements essential to these in the soil, starch, sugar and woody fibre, are perhaps formed; but no vegetable fibrine, albumen, or caseine. If we intend to produce on a given surface of soil more of these latter matters than the plants can obtain from the atmosphere or receive from the soil of the same surface in its uncultivated and normal state, we must *create* an artificial atmosphere, we must add the required elements to the soil.

The nourishment which must be supplied in a given time to different plants, in order to admit a free and unimpeded growth, is very unequal.

On dry sand, on pure calcareous soil, on naked rocks, only a few genera of plants prosper, and these are, for the most part, perennial plants. They require, for their slow growth, only such minute quantities of mineral substances as the soil can furnish, which may be totally barren for other species. Annual, and especially summer plants, grow and attain their perfection in a comparatively short time; they, therefore, do not prosper on a soil which is poor in those mineral substances necessary to their development. To attain a maximum in height in the short period of their existence, the nourishment contained in the atmosphere is not sufficient. If the end of cultivation is to be obtained, we must create in the soil an artificial atmosphere of carbonic acid and ammonia; and this surplus of nourishment, which the leaves cannot appropriate from the air, must be taken up by the corresponding organs, *i. e.* the roots, from the soil. But the ammonia, together with the carbonic acid, are alone insufficient to become part of a plant destined to the nourishment of animals. Without the alkalies, no albumen, without the alkaline and earthy phosphates, no vegetable fibrine, no vegetable caseine, can be formed. The phosphoric acid of the phosphate of lime, indispensable to the cerealia and other vegetables in the formation of their seeds, is separated as an excrement, in great quantities, by the rind and barks of ligneous plants.

How different are the evergreen plants, the cacti, the mosses, the ferns, and the pines, from our annual grasses, the cerealia and leguminous vegetables! The former, at every time of the day during winter and summer, obtain carbon through their leaves by absorbing carbonic acid which is not furnished by the barren soil on which they grow; water is also absorbed and retained by their coriaceous or fleshy leaves with great force. They lose very little by evaporation, compared with other plants. On the other hand, how very small is the quantity of mineral substances which they withdraw from the soil during their almost constant growth in one year, in comparison with the quantity which one crop of wheat of an equal weight receives in three months!

It is by means of moisture that plants receive the necessary alkalies and salts from the soil. In dry summers a phenomenon is observed, which, when the importance of mineral elements to the life of a plant was unknown, could not be explained. The leaves of plants first developed and perfected, and therefore nearer the surface of the soil, shrivel up and become yellow, lose their vitality, and fall off while the plant is in an active state of growth, without any visible cause. This phenomenon is not seen in moist years, nor in evergreen plants, and but rarely in plants which have long and deep roots, nor is it seen in perennials, save in autumn and winter.

The cause of this decay is now obvious. The perfectly-developed leaves absorb continually carbonic acid and ammonia from the atmosphere, which are converted into elements of new leaves, buds, and shoots; but this metamorphosis cannot be effected without the aid of the alkalies, and other mineral substances. If the soil is moist, the latter are continually supplied to an adequate amount, and the plant retains its lively green colour; but if this supply ceases, from a want of moisture, to dissolve the mineral elements, a separation takes place in the plant itself. The mineral constituents of the juice are withdrawn from the leaves already formed, and are used for the formation of the young shoots; and as soon as the seeds are developed, the vitality of the leaves completely ceases. These withered leaves contain only minute traces of soluble salts, while the buds and shoots are very rich in them.

On the other hand, it has been observed that, where a soil is too highly impregnated with soluble saline materials, these are separated upon the surface of the leaves. This happens to culinary vegetables especially, whose leaves become covered with a white crust. In consequence of these exudations the plant sickens, its organic activity decreases, its growth is disturbed; and if this state continues long, the plant dies. This is most frequently seen in foliaceous plants, the large surfaces of which evaporate considerable quantities of water. Carrots, pumpkins, peas, &c., are frequently thus diseased, when, after dry weather, the plant being near its full growth, the soil is moistened by short showers, followed again by dry weather. The rapid evaporation carries off the water absorbed by the root, and this leaves the salts in the plant in a far greater quantity than it can assimilate. These salts effloresce upon the surface of the leaves, and if they are herbaceous and juicy, produce an effect upon them as if they had been watered with a solution containing a greater quantity of salts than their organism can bear.

Of two plants of the same species, this disease befals that which is nearest its perfection; if one should have been planted later, or be more backward in its development, the same external cause which destroys the one will contribute to the growth of the other.*

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* In the Journal of the Royal Agricultural Society of England,

vol. xi., part II., there appeared last year a paper by Mr. Philip Pusey, on the progress of agricultural knowledge during the preceding eight years, in which, when considering the influence of chemistry upon agriculture, he concludes as follows : " The mineral theory, too hastily adopted by Liebig, namely, that the crops rise and fall in direct proportion to the quantity of mineral substances present in the soil, or to the addition or abstraction of these substances, which are added in the manure, has received its death-blow from the experiments of Mr. Lawes." " Mr. Lawes, our best authority," Mr. Pusey adds, " has *certainly* shown this much, that, of the two active ingredients of manure, the ammonia is especially suited to grain crops, the *phosphorus* for turnips, and that the woody matters of straw are *probably* advantageous for turnips. Except Liebig's recommendation to dissolve bones in sulphuric acid, and Sir Robert Kane's, to use flax-water as manure, there is," says Mr. Pusey, " no improvement in agriculture which has been derived from chemical discoveries." "It is a great mistake to suppose that we can make agriculturists by teaching them doubtful chemistry."—(P. 392.)

Those who should believe, in Germany and other countries, that the above remarks of the former president of the Royal Agricultural Society of England express the public opinion of England, would deceive themselves; and, as an honorary member of that society, I regard it as a point of honour to contradict directly the statements of Mr. Pusey. Mr. Pusey is not a chemist by profession, and the extent of his acquirements in chemistry as a science, is sufficiently shown by his statements in regard to the formation of fat, in the feeding of stock, from starch and sugar, which he declares, in the same paper, is denied by Boussingault and Dumas; as well as by his notion that gypsum must be dissolved in 500 parts of water before it can be transformed by the action of carbonate of ammonia into sulphate of ammonia and carbonate of lime. It is precisely M. Boussingault, who has given the strictest experimental proofs, that starch really possesses the property of becoming fat in the body of animals, and M. Dumas who has proved that sugar is converted into wax in the body of the bee; from which it does not of course follow, as Mr. Pusey supposes, that starch is to be given to animals by preference, with the view of producing fat. Moreover, it is known to every tyro in chemistry, that thousands of cwts. of sulphate of ammonia have been made by simply bringing powdered gypsum into contact with *carbonate of ammonia*, and that in the manufactory of Nussdorf, near Vienna, the same process—*treatment of gypsum with the distillate of putrid urine*—in all probability, is still employed.

Chemistry, during the last eight or ten years, has given to Agriculture the most complete explanations of the nutrition of plants and of the sources of their food; it has shown that plants must obtain, from the soil as well as from the atmosphere, a certain number of elements, if they are to be developed and to thrive on the soil; it has explained the causes of the advantage derived from the mechanical preparation of the soil, from quick-lime, from fallow, and from the rotation of crops. Chemistry, therefore, has given to Agriculture, the object of which is the profitable production of plants, during these years a scientific basis which it did not previously possess, and has thus supplied the first and most important condition of progress and of improvement. The fact that Mr. Pusey, in his article, which will be read with some astonishment in Germany and France, speaks of phosphorus (it ought to be phosphoric acid) and of ammonia, proves in the most striking manner the injustice of his assertions; for eight or ten years ago nothing was known in agriculture of phosphorus or of phosphate of lime, and nothing of ammonia. It was known, indeed, that bones had a good effect as manure, but no one knew what it was in the bones which really acted. Most agriculturists then believed that the good effects were to be ascribed to the organic matter, the gelatine of the bones; and the detection of this mistake is surely a great gain to agriculture. The nitrogen of plants was not then supposed to be derived from ammonia, but from the nitrogenous constituents of manure; and no intelligent person will deny that the discovery of the true origin of the nitrogen of plants, of its derivation from ammonia, has led to many most profitable applications. The farmer now knows how he must proceed, in order to fix this active ingredient in his manure, and at the present time it is the gas-works which enable him to fertilise his fields with it. Of all this, eight years before Mr. Pusey wrote, very little was known, and I consider myself therefore justified in declaring that the assertion of Mr. Pusey, "that chemistry, during that long period, has only given to agriculture a recipe for manuring turnips, and a new manure in flax-water," is erroneous. The recommendation to dissolve bones in sulphuric acid, or to use flax-water as manure, has, in a scientific sense, no greater value than a useful recipe for good blacking.

With regard to the experiments of Mr. Lawes, (the best authority, according to Mr. Pusey,) they are entirely devoid of value, as the foundation for general conclusions. With a knowledge of our experience of the effects of fallow, and of production on the large scale, it requires all the courage derived from a want of intimate acquaintance with the subject to assert, that *certainly* ammonia is peculiarly fitted for *grain* and *phosphorus* for *turnips*, and that manuring with straw is *probably* advantageous for turnips; for, not to speak of individual cases, in which these substances have been found to lead to an increase of produce, we might prove, exactly as Mr. Lawes has done, for a hundred thousand other fields, that these substances do not increase the crop, or even that they do not in any way affect it. At one time precisely similar conclusions were drawn with respect to the effects of gypsum and of nitrate of soda, and such conclusions in truth are only proofs how little those who draw them are acquainted with the true principles of agriculture. Everything, in the action of any manure, depends on the composition of the soil to which it is added. To fertilise a soil for grain by means of ammonia alone, is like trying to rear an ox with food from which the elements of his bones and his blood are excluded.

The opinion that potash, in many cases soda, lime, magnesia, phosphoric acid, sulphuric acid, iron, and (for the cerealia) alkaline silicates, are ingredients of a fertile soil; that these substances, along with certain constituents of the atmosphere, constitute the food of plants, and are as essential to them as bread and meat to men, or hay and oats to horses;—this opinion is not the expression of a theory, but of a natural law or universal fact. For such persons as understand the scope and bearing of such a law of nature, that indisputable axiom follows as a matter of course, which Mr. Pusey thinks the experiments of Mr. Lawes have annihilated; for it simply coincides with the familiar truth, that a purse of money becomes empty when the money is taken out of it and not returned; or that a man must be reduced to poverty, who consumes his capital instead of the interest.

The problem in agriculture, at the present day, is no longer to seek for proofs of this truth, which no man of science doubts; but the grand object is to substitute for farm-yard manure, that universal food of plants, its elements obtained from other and cheaper sources, retaining its full efficacy; and this can only be done when we shall have learned what as yet we know but imperfectly, how to give to an artificial mixture of the individual ingredients the mechanical form and chemical qualities essential to their reception and to their nutritive action on the plant; for without this form they cannot perfectly supply the place of farm-yard manure. All our labours must be devoted to the attainment of this important object.

The negative results of experiments, made without the guidance of just principles, do not gain in value by their multiplication; and millions of them do not outweigh one successful experiment, if the cause of its success be recognised and ascertained. It is perfectly clear that *unexplained* negative results, or failures, if they are to serve as foundation for an opinion, will yield proofs the more brilliant and striking, the more foolishly and thoughtlessly the experiments have been made; for in this case their irreconcileability with the opinion which they are to refute, is so much the greater. It is certain that the most accurate knowledge of mathematics and of the laws of physics and mechanics does not suffice to render a man an engineer, a machine-maker, or an astronomer; but to conclude from this that an acquaintance with mathematics, with the forces which produce mechanical motion, and with the laws of statics and dynamics is useless for the engineer, the machine-maker, and the astronomer, is as absurd as it would be to say that chemistry is not useful or necessary to the agriculturist. True it is, that chemistry is only then useful, when we have acquired a thorough knowledge of that science, and that it is perfectly useless to those, who do not understand it.

Every discovery, every improvement, every new truth in science, as in life, has two ordeals successively to pass through. In the first period of its existence it is proved that the new thing is not true or of no value, (let us call to mind the circulation of the blood, gas-light, cow-pox, steam-engines, &c., &c.). After it has fortunately got through this period, it is next proved that the new thing is not new, that it has been long known, that more than a hundred years ago there were people enough who knew it perfectly. It is only in the third period that the new truth bears its fruits. The truth, on which Mr. Lawes has inflicted the death-blow, is yet in its first stage, and my faith in it is such as to lead me to hope that I may be permitted to live to see it in its second and third stages.* It is Providence, of which Sir Robert Peel was only the instrument, which, by the abolition of the corn laws, has sent to the agriculturists of England necessity, the mother of invention and of progress, in order to force them to overcome the fear and repugnance they feel towards learning what is new. Let them not, however, deceive themselves by supposing that they can

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* I do not conceal from myself that the discredit into which the employment of the constituents of the ashes of plants, as manure, may have fallen in England, arises in part from the failure of the so-called Patent Mineral Manure. It was the discovery of a new and remarkable compound of carbonate of potash with carbonate of lime, which led, at that time, to the idea of the composition of this manure. And it was on account of this compound, which appeared likely to be of use in other ways, that, according to the custom of England, and by the advice of sagacious men, the manure was patented. The composition of the manure itself could be no secret, since every plant showed by its ashes the due proportion of the constituents essential to its growth. It was a circumstance deeply to be regretted, that the idea which this manure was intended to bring into operation, took the form of a commercial speculation. This, as I know for certain, was not the intention of the excellent persons who manufactured the manure; for, in regard to the commercial working of the patent, they did exactly the reverse of what would have been necessary to render it a source of profit. The idea was brought forth prematurely, and, as in the case of a child born before the time, death quickly followed.

I have, for three years past, on about twelve English acres of the most barren soil, near Giessen, by the use of a mineral manure, composed on the same principles, obtained, for all the crops which are cultivated in the district, results, which were declared, previous to my experiments, to be impossible, by all the agriculturists who knew the land. For what is called mineral manure, the time will perhaps yet come, when English agriculturists will send ships to Iceland or Sicily to bring from thence, for their corn-fields, cargoes of Palagonite (a mineral, which gelatinises even with acetic acid).

ever attain to real improvements, to real progress, or to the perfecting of agriculture, unless they acquire thorough and accurate knowledge of its principles. If they are not furnished with the capital of science, they will only waste their powers; sooner or later they must see that in this so called mineral theory, in its development and ultimate perfection, lies the whole future of agriculture.

I know that energetic and vigorous race of men, to which in its kind no other can be compared, the English yeomanry, and the wonders which they have accomplished by industry, exertion and perseverance. When the English farmer has acquired the insight which is still wanting, his iron will, strengthened by his motto, "Through," will conquer all the obstacles which exist between him and the light of science; and when that time comes, Great Britain will probably cease to import corn. There is no want of land or capital. The agriculturist must no longer calculate on protection; the time is past when the state ought to show or could show him any favour. When the state is shaken to its foundations by internal or external events, when commerce, industry, and all trades shall be at a stand, and perhaps on the brink of ruin; when the property and fortunes of all are shaken or changed, and the inhabitants of towns look forward with dread and apprehension to the future, then the agriculturist holds in his hand the key to the money chest of the rich, and the savings-box of the poor; for political events have not the slightest influence on the natural law, which forces man to take into his system, daily, a certain number of ounces of carbon and nitrogen. This is protection enough. Whatever else the agriculturist requires, he must find for himself.

LETTER XXXI.

HAVING, in several of the foregoing letters, attempted to lay before you my views concerning the different kinds of food, and the purposes which they have to fulfil in the animal organism, let me now direct your attention to a scarcely less interesting and equally important subject—the means of obtaining, from a given surface of the earth, the largest amount of produce adapted to the food of man and animals.

Agriculture is both a science and an art. The knowledge of all the conditions of the life of vegetables, the origin of their elements, and the sources of their nourishment, forms its scientific basis.

From this knowledge we derive certain rules for the exercise of the ART, the principles upon which the mechanical operations of farming depend, the usefulness or necessity of these for preparing the soil to support the growth of plants, and for removing every obnoxious influence. No experience, drawn from the exercise of the art, can be opposed to true scientific principles, because the latter should include all the results of practical operations, and are in some instances solely derived therefrom. Theory must correspond with experience, because it is nothing more than the reduction of a series of phenomena to their last causes.

A field in which we cultivate the same plant for several successive years becomes barren for that plant in a period varying with the nature of the soil: in one field it will be in three, in another in seven, in a third in twenty, in a fourth in a hundred years. One field bears wheat, and no peas; another beans or turnips, but no tobacco; a third gives a plentiful crop of turnips, but will not bear clover. What is the reason that a field loses its fertility for one plant, the same which at first flourished there? What is the reason one kind of plant succeeds in a field where another fails?

These questions belong to Science.

What means are necessary to preserve to a field its fertility for one and the same plant?—what to render one field fertile for two, for three, for all plants?

These last questions are put by Art, but they cannot be answered by Art.

If a farmer, without the guidance of just scientific principles, is trying experiments to render a field fertile for a plant which it otherwise will not bear, his prospect of success is very small. Thousands of farmers try such experiments in various directions, the result of which is a mass of practical experience forming a method of cultivation which accomplishes the desired end for certain places; but the same method frequently does not succeed, it indeed ceases to be applicable to a second or third place in the immediate neighbourhood. How large a capital, and how much power, are wasted in these experiments! Very different, and far more secure, is the path indicated by SCIENCE; it exposes us to no danger of failing, but on the contrary, it furnishes us with every guarantee of success. If the cause of failure—of barrenness in the soil for one or two plants—has been discovered, means to remedy it may readily be found.

The most exact observations prove that the method of cultivation must vary with the geognostical condition of the subsoil. In basalt, graywacke, porphyry, sandstone, limestone, &c., are certain elements indispensable to the growth of plants, and the presence of which renders the soil fertile. This fully explains the difference in the necessary methods of culture for different places; since it is obvious that the essential elements of the soil must vary with the varieties of composition of the rocks, from the disintegration of which they originated.

Wheat, clover, turnips, for example, each require certain elements from the soil; they will not flourish where the appropriate elements are absent. Science teaches us what elements are essential to every species of plants by an analysis of their ashes. If therefore a soil is found wanting in any of those elements, we discover at once the cause of its barrenness, and its removal may now be readily accomplished.

The empiric attributes all his success to the mechanical operations of agriculture; he experiences and recognises their value, without inquiring what are the causes of their utility; their mode of action: and yet this scientific knowledge is of the highest importance for regulating the application of power and the expenditure of capital,—for ensuring its economical expenditure and the prevention of waste. Can it be imagined that the mere passing of the ploughshare or the harrow through the soil—the mere contact of the iron—can impart fertility as by a charm? Nobody, perhaps, seriously entertains such an opinion. Nevertheless, the *modus operandi* of these mechanical operations is by no means generally understood. The fact is quite certain, that careful ploughing exerts the most favourable influence: the surface is thus mechanically divided, changed, increased, and renovated; but the ploughing is only auxiliary to the end sought.

Among the effects of time, in what in Agriculture are technically called *fallows*—the repose of the fields—are included by science certain chemical actions, which are continually exercised by the elements of the atmosphere upon the whole surface of our globe. By the action of its oxygen and its carbonic acid, aided by water, rain, changes of temperature, &c., certain elementary constituents of rocks, or of their ruins, which form the soil capable of cultivation, are rendered soluble in water, and consequently become separable from all their insoluble parts.

These chemical actions, poetically denominated the "tooth of time," destroy all the works of man, and gradually reduce the hardest rocks to the condition of dust. By their influence the necessary elements of the soil become fitted for assimilation by plants; and it is precisely this end which is obtained by the mechanical operations of farming. They accelerate the decomposition of the soil, in order to provide a new generation of plants with the necessary elements in a condition favourable to their assimilation. It is obvious that the rapidity of the decomposition of a solid body must increase with the extension of its surface; the more points of contact we offer in a given time to the external chemical agent, the more rapid will be its action.

The chemist, in order to prepare a mineral for analysis, to decompose it, or to increase the solubility of its elements, proceeds in the same way as the farmer deals with his fields—he spares no labour in order to reduce it to the finest powder; he separates the impalpable from the coarser parts by washing, and repeats his mechanical bruising and trituration, being assured his whole process will fail if he is inattentive to this essential and preliminary part of it.

The influence which the increase of surface exercises upon the disintegration of rocks, and upon the chemical action of air and moisture, is strikingly illustrated upon a large scale in the operations pursued in the gold-mines of Yaquil, in Chili. These are described in a very interesting manner by Darwin. The rock containing the gold ore is pounded by mills into the finest powder; this is subjected to washing, which separates the lighter particles from the metallic; the gold sinks to the bottom, while a stream of water carries away the lighter earthy parts into ponds, where it subsides to the bottom as mud. When this deposit has gradually filled up the pond, this mud is taken out and piled in heaps, and left exposed to the action of the atmosphere and moisture. The washing completely removes all the soluble part of the disintegrated rock; the insoluble part, moreover, cannot undergo any further change while it is covered with water, and so excluded from the influence of the atmosphere at the bottom of the pond. But being exposed at once to the air and to moisture, a powerful chemical action takes place throughout the whole mass, which becomes indicated by an efflorescence of salts covering the whole surface of the heaps in considerable quantity. After being exposed for two or three years, the mud is again subjected to the same process of washing, and a considerable quantity of gold is obtained, this having been separated by the chemical process of decomposition in the mass. The exposure and washing of the same mud is repeated six or seven times, and at every washing it furnishes a new quantity of gold, although its amount diminishes every time.

Precisely similar is the chemical action which takes place in the soil of our fields; and we accelerate and increase it by the mechanical operations of agriculture. By these we divide and extend the surface, and endeavour to make every atom of the soil accessible to the action of the carbonic acid and oxygen of the atmosphere. We thus produce a stock of soluble mineral substances, which serve as nourishment to a new generation of plants, materials which are indispensable to their growth and prosperity.

LETTER XXXII.

HAVING in my last letter spoken of the general principles upon which the science and art of agriculture must be based, let me now direct your attention to some of those particulars which will more forcibly exhibit the connexion between chemistry and agriculture, and demonstrate the impossibility of perfecting the important art of rearing food for man and animals, without a profound knowledge of our science.

All plants cultivated as food require for their healthy sustenance the alkalies and alkaline earths, each in a certain proportion; and in addition to these, the cerealia do not succeed in a soil destitute of *silica* in a soluble condition. The combinations of this substance found as natural productions, namely, the silicates, differ greatly in the degree of facility with which they undergo decomposition, in consequence of the unequal resistance opposed by their integral parts to the dissolving power of the atmospheric agencies. Thus the granite of Corsica degenerates into a powder in a time which scarcely suffices to deprive the polished granite of Heidelberg of its lustre.

Some soils abound so much in readily decomposable silicates, that, after every one or two years, as much silicate of potash has become soluble and fitted for assimilation as is required by the leaves and straw of a crop of wheat. In Hungary, extensive districts are not uncommon where wheat and tobacco have been grown alternately upon the same soil for centuries, the land never receiving back any of those mineral elements which were withdrawn in the grain and leaves. On the other hand, there are fields in which the necessary amount of soluble silicate of potash for a single crop of wheat is not separated from the insoluble masses in the soil in less than two, three, or even more years.

The term *fallow*, in agriculture, designates that period in which the soil, left to the influence of the atmosphere, becomes enriched with those soluble mineral constituents. *Fallow*, however, does not generally imply an entire cessation of cultivation, but only an interval in the growth of the cerealia. That store of soluble silicates and alkalies which is the principal condition of their success, is obtained if potatoes or turnips are grown upon the same fields in the intermediate periods, since these crops do not abstract a particle of silica, and therefore leave the field equally fertile for the following crop of wheat.

The preceding remarks will render it obvious to you, that the mechanical working of the soil is the simplest and cheapest method of rendering the elements of nutrition contained in it accessible to plants.

But it may be asked, " Are there not other means of decomposing the soil besides its mechanical subdivision ?—Are there not substances, which, by their chemical operation, will equally well, or better, render its constituents suitable for entering into vegetable organisms ? " Yes ; we certainly possess such substances, and one of them, namely, *quick-lime*, has been employed for a century past in England for this purpose ; and it would be difficult to find a substance better adapted to this service, as it is simple, and in almost all localities cheap and easily accessible.

In order to obtain correct views respecting the effect of quick-lime upon the soil, let me remind you of the first process employed by the chemist when he is desirous of analysing a mineral, and for this purpose wishes to bring its elements into a soluble state. Let the mineral to be examined be, for instance, felspar ; this substance, taken alone, even when reduced to the finest powder, requires for its solution to be treated with an acid for weeks or months; but if we first mix it with quick-lime, and expose the mixture to a moderately strong heat, the lime enters into chemical combination with certain elements of the felspar, and its alkali (potass) is set free. And now the acid, even without heat, dissolves not only the lime, but also so much of the *silica* of the felspar as to form a transparent jelly. The same effect which the lime in this process, with the aid of heat, exerts upon the felspar, it produces when it is mixed with the alkaline argillaceous silicates, and they are for a long time kept together in a moist state.

Common potters' clay, or pipe-clay, diffused through water, and added to milk of lime, thickens immediately upon mixing; and if the mixture be kept for some months, and then treated with acid, the clay becomes gelatinous, which would not occur without the admixture with the lime. The lime, in combining with the elements of the clay, renders it soluble; and, what is more remarkable, liberates the greater part of its alkalies. These interesting facts were first observed by Fuchs, at Munich; they have not only led to a more intimate knowledge of the nature and properties of the hydraulic cements, but, what is far more important, they explain the effects of caustic lime upon the soil, and guide the agriculturist in the application of an invaluable means of rendering it soluble, and setting free its alkalies,—substances so important, nay, so indispensable to his crops.

In the month of October, the fields of Yorkshire and Herefordshire look as if they were covered with snow. Whole square miles are seen whitened over with quick-lime, which, during the moist winter months, exercises its beneficial influence upon the stiff clay soil of those counties.

According to the now abandoned humus theory, quick-lime ought to exert the most noxious influence upon the soil, because all organic matters contained in it are destroyed by lime, and rendered incapable of yielding their humus to a new vegetation. The facts are indeed directly contrary to this now abandoned theory; the fertility of the soil for the cerealia is increased by the lime. The cerealia require the alkalies and soluble silicates, which the action of the lime renders fit for assimilation by the plants. If, in addition to these, there is any decaying organic matter present in the soil supplying carbonic acid, it may facilitate their development; but it is not essential to their growth. If we furnish the soil with ammonia, and the phosphates which are indispensable to the cerealia, with the alkaline silicates, we have all the conditions necessary to insure an abundant harvest. The atmosphere is an inexhaustible store of carbonic acid.

A no less favourable influence than that of lime is exercised upon the soil of peaty land by the mere act of burning it. This greatly enhances its fertility. We have not long been acquainted with the remarkable change which the properties of clay undergo by burning. The observation was first made in the process of analysing the clay silicates. Many of these, in their natural state, are not acted on by acids, but they become perfectly soluble if heated to redness before the application of the acid. This property belongs to potters' clay, pipe-clay, loam, and many different modifications of clay in soils. In their natural state they may be boiled in concentrated sulphuric acid, without sensible change; but if gently calcined, as is done with the pipe-clay in many alum manufactories, they dissolve in the acid with the greatest facility, the contained silica being separated like a jelly in a soluble state. Potters' clay belongs to the most sterile kinds of soil, and yet it contains within itself all the constituent elements essential to a most luxurious growth of plants; but their mere presence is insufficient to secure this end. The soil must be accessible to the atmosphere, to its oxygen, to its carbonic acid; these must penetrate it, in order to secure the conditions necessary to a happy and vigorous development of the roots. The elements present must be brought into that peculiar state of combination which will enable them to enter into plants. Plastic clay is wanting in these properties; but they are imparted to it by a gentle calcination.

At Hardwicke Court, near Gloucester, I have seen a garden (Mr. Baker's) consisting of a stiff clay, which was perfectly sterile, become, by mere burning, extremely fertile. The operation was extended to a depth of three feet. This was an expensive process, certainly; but it was effectual.

The great difference in the properties of burnt and unburnt clay is illustrated by what is seen in brick houses built in moist situations. In the towns of Flanders, for instance, where most buildings are of brick, efflorescences of salts cover the surfaces of the walls, like a white crust, within a few days after they are erected. If this saline incrustation is washed away by the rain, it soon re-appears; and this is even observed on walls which, like the gateway of Lisle, have stood for centuries. These saline incrustations consist of carbonates and sulphates, with alkaline bases; and it is well known these act an important part in vegetation. The influence of lime in their production is manifested by their appearing first at the place where the mortar and brick come into contact.

It will now be obvious to you, that in a mixture of clay with lime, all the conditions exist for the decomposition of the silicated clay, and the rendering soluble of the alkaline silicates. The lime gradually dissolving in water charged with carbonic acid, acts like milk of lime upon the clay. This explains also the favourable influence which *marl* (by which term all those varieties of clay rich in lime are designated) exerts upon most kinds of soil. There are marly soils which surpass all others in fertility for all kinds of plants; but I believe marl in a burnt state must be far more effective, as well as other materials possessing a similar composition; as, for instance, those species of limestone which are adapted to the preparation of hydraulic cements,—for these carry to the soil not only the alkaline bases useful to plants, but also silica in a state capable of assimilation.

The ashes of coals and lignite are also excellent means of ameliorating the soil, and they are used in many places for this purpose. The most suitable may be readily known by their property of forming a gelatinous mass when treated with acids, or by becoming, when mixed with cream of lime, like hydraulic cement,—solid and hard as stone.

I have now, I trust, explained to your satisfaction, that the mechanical operations of agriculture—the application of lime and chalk to lands, and the burning of clay—depend upon one and the same scientific principle: they are means of accelerating the decomposition of the alkaline clay silicates, in order to provide plants, at the beginning of a new vegetation, with certain inorganic matters indispensable for their nutrition.

LETTER XXXIII.

I TREATED, in my last letter, of the means of improving the condition of the soil for agricultural purposes by mechanical operations and mineral agents. I have now to speak of the uses and effects of animal exuviæ, and vegetable matters or *manures*—properly so called.

In order to understand the nature of these, and the peculiarity of their influence upon our fields, it is highly important to keep in mind the source whence they are derived.

It is generally known, that if we deprive an animal of food, the weight of its body diminishes during every moment of its existence. If this abstinence is continued for some time, the diminution becomes apparent to the eye; all the fat of the body disappears, the muscles decrease in size and finally disappear, and, if the animal is allowed to die starved, scarcely anything but skin, tendon, and bones remain. This emaciation, which occurs in a body otherwise healthy, demonstrates to us, that during the life of an animal every part of its living substance is undergoing a perpetual change; all its component parts, assuming the form of lifeless compounds, are thrown off by the skin, lungs, and urinary system, altered more or less by the secretory organs. This change in the living body is intimately connected with the process of respiration; it is, in truth, occasioned by the oxygen of the atmosphere in breathing, which combines with all the various matters within the body. At every inspiration a quantity of oxygen passes into the blood in the lungs, and unites with its elements; but although the weight of the oxygen thus daily entering into the body amounts to 32 or more ounces, yet the weight of the body is not thereby increased. Exactly as much oxygen as is imbibed in inspiration passes off in expiration, in the form of carbonic acid and water; so that with every breath the amount of carbon and hydrogen in the body is diminished. But the emaciation—the loss of weight by starvation—does not simply depend upon the separation of the carbon and hydrogen; for all the other substances which are in combination with these elements in the living tissues pass off in the secretions. The nitrogen undergoes a change, and is thrown out of the system by the kidneys. Their secretion, the urine, contains not only a compound rich in nitrogen, namely urea, but the sulphur of the tissues in the form of a sulphate, all the soluble salts of the blood and animal fluids, common salt, the phosphates, soda, and potash. The carbon and hydrogen of the blood, of the muscular fibre, and of all the animal tissues which can undergo change, return into the *atmosphere*. The nitrogen, and all the soluble inorganic elements, are carried to the *earth* in the urine.

These changes take place in the healthy animal body during every moment of life; a waste and loss of substance proceeds continually; and if this loss is to be restored, and the original weight and substance repaired, an adequate supply of materials must be furnished, from whence the blood and wasted tissues may be regenerated. This supply is obtained from the food.

In an adult person in a normal or healthy condition, no sensible increase or decrease of weight occurs from day to day. In youth the weight of the body increases, whilst in old age it decreases. There can be no doubt that, in the adult, the food has exactly replaced the loss of substance: it has supplied just so much carbon, hydrogen, nitrogen, and other elements, as have passed through the skin, lungs, and urinary organs. In youth the supply is greater than the waste. Part of the elements of the food remain to augment the bulk of the body. In old age the waste is greater than the supply, and the body diminishes. It is unquestionable, that, with the exception of a certain quantity of carbon and hydrogen, which are secreted through the skin and lungs, we obtain, in the solid and fluid excrements of man and animals, all the elements of their food.

We obtain daily, in the form of urea, all the nitrogen taken in the food, both of the young and the adult; and further, in the urine, the whole amount of the alkalies, soluble phosphates and sulphates, contained in all the various aliments. In the solid excrements are found a number of substances taken in the food, which have undergone no alteration in the digestive organs, all indigestible matters, such as woody fibre, the green colouring matter of leaves (chlorophylle), wax, &c.

Physiology teaches us, that the process of nutrition in animals, that is, their increase of bulk, or the restoration of wasted parts, proceeds from the blood. The purpose of digestion and assimilation is to convert the food into blood. In the stomach and intestines, therefore, all those substances in the food capable of conversion into blood are separated from its other constituents; in other words, during the passage of the food through the intestinal canal there is a constant absorption of its nitrogen, since only azotised substances are capable of conversion into blood; and therefore the solid excrements are destitute of that element, except only a small portion, in the constitution of that secretion which is formed to facilitate their passage. With the solid excrements, the phosphates of lime and magnesia, which were contained in the food and not assimilated, are carried off, these salts being insoluble in water, and therefore not entering the urine.

We may obtain a clear insight into the chemical constitution of the solid excrements without further investigation, by comparing the fæces of a dog with his food. We give that animal flesh and bones—substances rich in azotised matter—and we obtain, as the last product of its digestion, a perfectly white excrement, solid while moist, but becoming in dry air a powder. This is the phosphate of lime of the bones, with scarcely one per cent. of foreign organic matter.

Thus we see that in the solid and fluid excrements of man and animals, all the nitrogen—in short, all the constituent ingredients of the consumed food, soluble and insoluble, are returned; and as food is primarily derived from the fields, we possess in those excrements all the ingredients which we have taken from it in the form of seeds, roots, or herbs.

One part of the crops employed for fattening sheep and cattle is consumed by man as animal food; another part is taken directly—as flour, potatoes, green vegetables, &c.; a third portion consists of vegetable refuse, and straw employed as litter. None of the materials of the soil need be lost. We can, it is obvious, get back all its constituent parts which have been withdrawn therefrom, as fruits, grain, and animals, in the fluid and solid excrements of man, and the bones, blood, and skins of the slaughtered animals. It depends upon ourselves to collect carefully all these scattered elements, and to restore the disturbed equilibrium of composition in the soil. We can calculate exactly how much and which of the component parts of the soil we export in a sheep or an ox, in a quarter of barley, wheat, or potatoes, and we can discover, from the known composition of the excrements of man and animals, how much we have to supply to restore what is lost to our fields.

If, however, we could procure from other sources the substances which give to the exuviæ of man and animals their value in agriculture, we should not need the latter. It is quite indifferent for our purpose whether we supply the ammonia (the source of nitrogen) in the form of urine, or in that of a salt derived from coal-tar; whether we derive the phosphate of lime from bones, apatite, or fossil excrements (the coprolites).*

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* When Dr. Daubeny (Professor in Oxford, known by his distinguished work on volcanoes,) had convinced himself, by a series of his own experiments, of the use and the importance of phosphate of lime for vegetation, his attention turned to the extensive formation of phosphate of lime, which, according to respectable authors on mineralogy, occurs in some parts of the Spanish province

The principal problem for agriculture is, how to replace those substances which have been taken from the soil, and which cannot be furnished by the atmosphere. If the manure supplies an imperfect compensation for this loss, the fertility of a field or of a country decreases; if, on the contrary, more are given to the fields, their fertility increases.

An importation of urine, or of solid excrements, from a foreign country, is equivalent to an importation of grain and cattle. In a certain time, the elements of those substances assume the form of grain, or of fodder, then become flesh and bones, enter into the human body, and return again day by day to the form they originally possessed.

The only real loss of elements we are unable to prevent is of the phosphates, in so far as these, in accordance with the customs of all modern nations, are deposited

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of Estremadura. He made a pilgrimage along with Captain Widdrington, to that country, to satisfy himself "whether the situation of the mineral in question were adapted for supplying the fields of England with phosphate of lime, in case other sources of it should be dried up." I mention this as one of the numerous proofs of the feeling entertained by the English for the prosperity of their country, and because such a devotion to science, without inducement on the part of government, and without the prospect of reward from the country, is so seldom seen in other countries.

To this journey we owe an authentic report on the occurrence of this most valuable mineral, which forms, in Estremadura, near Logrosan, seven miles from Truxillo, a bed or vein from 7 to 16 feet wide, and several miles in length. This is one of the treasures, of which Spain has so many, sufficient perhaps, at no distant period, to pay a part of the national debt of that country. It is deeply to be regretted that the railways, projected seven years ago, which, crossing each other at Madrid as a centre, were to unite Portugal with France, and Madrid with both seas, have not been executed. These railways would render Spain the richest country in Europe.

Near Ostheim, in the Wetterau, Dr. Bromeis has lately discovered a layer of phosphate of lime (osteolite) 6 inches thick, in decomposed dolerite. The osteolite is snow-white, comes off on the hand like chalk, and contains 86 per cent. of pure phosphate of lime.

in the grave. For the rest, every part of that enormous quantity of food which a man consumes during his lifetime (say in sixty or seventy years), which was derived from the fields, can be obtained and returned to them. We know, with absolute certainty, that we receive back, in the solid and fluid excrements, all the salts and alkaline bases, all the phosphate of lime and magnesia, and consequently all the inorganic elements, which the animal consumes in its food.

We can thus ascertain precisely the quantity, quality, and composition of animal excrements, without the trouble of analysing them. If we give a horse daily 4½ pounds weight of oats, and 15 pounds of hay, and, knowing that oats give 4 per cent. and hay 9 per cent. of ashes, we can calculate that the daily excrements of the horse will contain 21 ounces of inorganic matter which was drawn from the fields. By analysis we can determine the exact relative amount of silica, of phosphates, and of alkalies, contained in the ashes of the oats and of the hay.

You will now understand that the constituents of the solid parts of animal excrements, and therefore their qualities as manure, must vary with the nature of the food. If we feed a cow upon beetroot, or potatoes, without hay, straw, or grain, there will be no silica in her solid excrements, but there will be phosphate of lime and magnesia. Her fluid excrements will contain carbonate of potash and soda, together with compounds of the same bases with inorganic acids. In one word, we have, in the fluid excrements, all the soluble parts of the ashes of the consumed food; and in the solid excrements, all those parts of the ashes which are insoluble in water.

If the food, after burning, leaves behind ashes containing soluble alkaline phosphates, as is the case with bread, meal, seeds of all kinds, and flesh, we obtain from the animal by which they are consumed a urine holding in solution these phosphates. If, however, the ashes of food contain no alkaline phosphates, but abound in insoluble earthy phosphates, as hay, clover, and straw, the urine will be free from alkaline phosphates, but the earthy phosphates will be found in the fæces. The urine of man, of carnivorous and graminivorous animals, contains alkaline phosphates; that of herbivorous animals is free from these salts.

The analysis of the excrements of man, of the piscivorous birds (as the *guano*), of the horse, and of cattle, furnishes us with the precise knowledge of the salts they contain, and demonstrates that in those excrements we return to the fields *the ashes of the plants which have served as food*,—the soluble and insoluble salts and earths indispensable to the development of cultivated plants, and which must be furnished to them by a fertile soil.

There can be no doubt that, in supplying these excrements to the soil, we return to it those constituents which the crops have removed from it, and we renew its capability of nourishing new crops: in one word, we restore the disturbed equilibrium; and consequently, knowing that the elements of the food derived from the soil enter into the urine and solid excrements of the animals it nourishes, we can with the greatest facility determine the exact value of the different kinds of manure. The solid and liquid excreta of an animal have the highest value as manure for those plants on which the animal has fed. Thus the excrements of pigs which we have fed with peas and potatoes are principally suited for manuring crops of potatoes and peas. In feeding a cow upon hay and turnips, we obtain a manure containing the inorganic elements of grasses and turnips, and which is therefore preferable for manuring turnips. The excrement of pigeons contains the mineral elements of grain; that of rabbits, the elements of herbs and kitchen vegetables. The fluid and solid excrements of man, however, contain the mineral elements of grain and seeds in the greatest quantity.*

LETTER XXXIV.

You are now acquainted with my opinions respecting the effects of the application of mineral agents to our cultivated fields, and also the rationale of the influence of the various kinds of manures; you will, therefore, now readily understand what I have further to say of the sources whence the carbon and nitrogen, indispensable to the growth of plants, are derived.

The growth of forests, and the produce of meadows, demonstrate that an inexhaustible quantity of carbon

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* On a piece of land near Giessen, of the very worst quality, on which for centuries past only firs had grown, and which as arable land hardly possessed a value, I have made during three years a series of experiments on the action of the mineral ingredients of manure, and have satisfied myself that for perennial plants, such as wood and vines, the ingredients of their ashes, from any source, suffice to render the soil fertile for these plants; but that for corn and summer plants, in order to obtain a maximum of produce, the presence of organic matter in the soil is of the utmost value. By the addition of sawdust the effect of the mineral manure was strikingly augmented, and it appears to me to be clear that the chief cause of this increased action must be looked for in the carbonic acid formed by the decay of the wood, which (the carbonic acid) in this case acts not nearly so much as a source of carbon, as by its *solvent power* for the earthy phosphates (of lime and magnesia), and by converting into bicarbonates the neutral alkaline and earthy carbonates. This carbonic acid is the condition furnished by nature for the passage of these necessary parts of the food of plants into their organism; for the earthy phosphates and carbonates are

is furnished for vegetation by the carbonic acid of the atmosphere.

We obtain from an equal surface of forest or meadow land, where the necessary mineral elements of the soil are present in a suitable state, and to which no carbonaceous matter whatever is furnished in manures, an amount of carbon, in the shape of wood and hay, quite equal to, and ofttimes greater than that which is produced by our fields, in the grain, roots, and straw, upon which abundance of manure has been heaped.

It is perfectly obvious that the atmosphere must

only soluble in water when the water contains carbonic acid. The carbonic acid contained in rain-water is obviously not sufficient to bring into the soluble form, which alone is fitted for assimilation by vegetables, the proportionally large amount of mineral substances; which is absolutely necessary to obtain a maximum of development in summer plants, such as grain, *during the short period of their growth*. It is well known how great is the effect produced in this way even by moderate rains; and we may easily calculate how greatly this action must be increased by the addition of carbonic acid, whereby the solvent power of rain-water for these mineral substances is augmented a hundred, nay, a thousand fold. The carbonic acid of ordinary spring-water, which often retains in solution such considerable quantities of inorganic matter, proceeds from the same source, namely, the decay of organic matter in the soil.*

The greatest effect was obtained from a mixture of farm-yard

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* In proof of the remarkable solvent power of rain-water for phosphate of lime, especially after the water has filtered through soil containing more or less decaying organic matter, I may adduce the following fact:—A fat pig, of full size, having been wounded, became sick and died; it was buried on the slope of a rising ground, undrained and naturally moist; and when the grave was opened, after 14 or 15 years, there was found a thin, flat cake, white internally, where the body had lain, in length and breadth corresponding to the size of the pig. This I found to consist entirely of fatty acids nearly pure; and it did not contain even a trace of bone earth, its ashes being quite insignificant in quantity, and consisting of carbonate of lime and a little silica, evidently from the external coating. The interior left hardly a trace of ash. Here, in circumstances favourable to perpetual renewal of rain-water, the bones had been entirely removed, and carried to the low grounds. It would appear from this, that if churchyards were placed in similar situations, even the phosphates buried with our bodies would be recovered in a great measure, and fertilise the lower levels.—W. G.

furnish to our cultivated fields as much carbonic acid as it does to an equal surface of forest or meadow, and that the carbon of this carbonic acid is assimilated, or may be assimilated, by the plants growing there, provided the conditions essential to its assimilation, and to its becoming a constituent element of vegetables, are found united in the soil of these fields.

With the fullest supply of nutritive matters, a soil is, for most plants, quite barren, if water be wanting,

manure and mineral manure; the former contains too much organic matter in reference to its mineral ingredients; so much, at all events, that the carbonic acid formed in its decay could dissolve many times more of the mineral substances. The extraordinary increase of the effect from bones by the addition of sulphuric acid depends entirely on the increased solubility of the phosphate of lime. In my experiments I found, as many have done before me, that the fertilisation of so barren a soil, when its barrenness depends on the absence of the essential active substances, and not on a mechanical or physical unfitness, compels an expenditure greater than would be required to purchase the same amount of fertile land. It is easy to make the calculation.

If to one acre, English, we add 8950 lbs. (about 4 tons) of the ashes (or of the ingredients of these ashes from other sources), of wheat, potatoes, &c., this large supply only suffices to give to the soil of the whole surface, to the depth of one foot, these materials in the proportion of one grain to each cubic foot. This is much less than is contained in a cubic foot of tolerably fertile soil; but, on the other hand, much more than is required for one crop. But since only that part of the manure acts which is in contact with the fibres of the roots, it is easy to see why so much must be given at first. It would appear that, in many cases, the chief effect of manure on our fields consists in this, that in consequence of the more abundant nutrition in the upper crust of the field, the plants during the first period of their growth push out ten times, perhaps, a hundred or a thousand times more root-fibres than they would have done in poor soil; and that their subsequent growth is in proportion to the number of these organs, by means of which they are enabled to search for and assimilate the less abundant food in the deeper strata. This may perhaps explain how a quantity of the constituents of manure, ammonia, alkalies, and earthy phosphates, so small in proportion to the amount of the same matters diffused through the soil, increases the fertility in so remarkable a degree.

especially at certain seasons. Rain fertilises our fields; the seed does not germinate and is not developed without the presence of a certain amount of moisture.

The fertilising effect of rain is, on a superficial examination, still more wonderful and more surprising than that of manure. Its influence on the produce of a field is observable during weeks and months after it has fallen; and yet rain conveys to plants only very small quantities of carbonic acid and ammonia. The plant receives by the medium of water at the time of its first development, the alkalies, alkaline earths, and phosphates necessary to its organisation. If these elements, which are necessary previous to its assimilation of atmospheric nourishment, be absent, its growth is retarded. In fact, the development of a plant, during the subsequent dry season, is in a direct ratio to the amount of the matters it has taken up from the soil during the period of its first development. If a soil be deficient in these mineral constituents required by our cultivated plants, they will not flourish, even with an abundant supply of water.

The produce of carbon on a meadow, or an equal surface of forest land, is independent of a supply of carbonaceous manure, but it depends upon the presence of certain elements of the soil which in themselves contain no carbon, together with the existence of conditions under which their assimilation by plants can be effected. We increase the produce of carbon in our cultivated fields by a supply of lime, ashes, and marl, substances which cannot furnish carbon to the plants; and yet it is indisputable,—being founded upon abundant experience,—that in these substances we furnish to the fields elements which greatly increase the bulk of their produce, and consequently the amount of carbon.

If we admit these facts to be established, we can no longer doubt that a deficient produce of carbon, or, in other words, the barrenness of a field, does not depend upon a deficiency of carbonic acid or of humus, because we are able to increase the produce, to a certain degree, by a supply of substances which do not contain any carbon. The same source whence the meadow and the forest are furnished with carbon, is also open to our cultivated plants. The great object of agriculture, therefore, is to discover the means best adapted to enable these plants to assimilate the carbon of the atmosphere which exists in it as carbonic acid. In furnishing plants, therefore, with mineral elements, we give them the power to appropriate carbon from a source which is inexhaustible; whilst in the absence of these elements the most abundant supply of carbonic acid, or of decaying vegetable matter,, would not increase the produce of a field.

With an adequate supply of these essential mineral constituents in the soil, the amount of carbonic acid absorbed by a plant from the atmosphere in a given time is limited by the quantity which is brought into contact with its organs of absorption.

The withdrawal of carbonic acid from the atmosphere by the vegetable organism takes places chiefly through its leaves; this absorption requires the contact of the carbonic acid with their surface, or with the part of the plant by which it is absorbed.

The quantity of carbonic acid absorbed in a given time is in direct proportion to the surface of the leaves and the amount of carbonic acid contained in the air; that is, two plants of the same kind and the same extent of surface of absorption, in equal times and under equal conditions, absorb one and the same amount of carbon.

In an atmosphere containing a double proportion of carbonic acid, a plant absorbs, under the same condition, twice the quantity of carbon. Boussingault observed, that the leaves of the vine, inclosed in a vessel, withdrew all the carbonic acid from a current of air which was passed through it, however great its velocity. (Dumas, Leçon, p. 23.) If, therefore, we supply double the quantity of carbonic acid to one plant, the extent of the surface of which is only half that of another living in ordinary atmospheric air, the former will obtain and appropriate as much carbon as the latter. Hence result the beneficial effects of humus, and all decaying organic substances, upon our cultivated plants. If we suppose all the conditions for the absorption of carbonic acid present, a young plant will increase in mass, in a limited time, only in proportion to its absorbing surface; but if we create in the soil a new source of carbonic acid, by decaying vegetable substances, and the roots absorb in the same time three times as much carbonic acid from the soil as the leaves derive from the atmosphere, the plant will increase in weight fourfold. This fourfold increase extends to the leaves, buds, stalks, &c., and in the increased extent of surface the plant acquires an increased power of absorbing nourishment from the air, which continues in action far beyond the time when its derivation of carbonic acid through the roots ceases. Humus, as a source of carbonic acid in cultivated lands, is not only useful as a means of increasing the quantity of carbon, but the mass of the plant having increased rapidly in a short time, space is obtained for the assimilation of the elements of the soil necessary for the formation of new leaves and branches.

Water evaporates incessantly from the surface of the young plant; its quantity is in direct proportion to the temperature and the extent of the surface. The numerous radical fibrillæ replace, like so many pumps, the evaporated water; and so long as the soil is moist, or penetrated with water, the indispensable elements of the soil, dissolved in the water, are supplied to the plant. From a plant with double the surface, twice as much water evaporates as from another the surface of which is half that of the former. The water absorbed by the plant evaporating in an aëriform state, leaves the saline and other mineral constituents within it. The relative proportion of these elements taken up by a plant is greater the more extensive the surface and more abundant the supply of water; where these are limited, the plant soon reaches its full growth; while, in the other, a greater amount of elements necessary to enable it to appropriate atmospheric nourishment, having been obtained, its development continues much longer. The quantity, or mass of seed produced, will correspond to the quantity of mineral constituents present in the plant. That plant, therefore, containing the most *alkaline phosphates* and *earthy salts*, will produce more, or a greater weight of, seeds than another which, in an equal time, has absorbed less of them. We consequently observe, in a hot summer, when a further supply of mineral ingredients from the soil ceases through want of water, that the height and strength of plants, as well as the development of their seeds, are in direct proportion to their absorption of the elementary parts of the soil in the preceding epochs of their growth.

On one and the same field we raise, in different years, very different proportions of grain and straw. For equal weights of grain, of the same chemical composition, the gross produce (of grain and straw) is, in one year, one-half greater than in another; or, for equal weights of straw (carbon), we obtain in one year twice as much grain as in the other.

But if we raise, from the same surface, twice as much grain, we have in this grain a corresponding excess of mineral elements. If the produce in straw be double, we have a double quantity of the mineral elements of straw.

In one year, wheat grows three feet high, and yields from each morgen (an acre nearly) 1200 lbs. of grain; next year it grows four feet high, and yields only 800 lbs. of seeds.

The inequality in the produce corresponds, under all circumstances, to the unequal proportion of the mineral elements of the grain and of the straw taken up by the wheat. Straw contains and requires the phosphates as well as grain, but in smaller proportion. If, in a moist spring, the supply of phosphates be not in proportion to that of the alkalies, of silicic acid, and of the sulphates; if the latter be in greater proportion than the phosphates, the produce of carbon increases, and a much larger proportion than usual of phosphates is employed in the formation of leaves and stalks. Without an excess of phosphates beyond this, the seed is not fully developed. Nay, we can, merely by excluding these salts beyond a certain proportion, cause the occurrence of an artificial case, in which the plant reaches a height of three feet, and flowers, without bearing any seeds. On a soil rich in the mineral elements of straw (a fat soil), we obtain, after a wet spring, proportionally less grain than on a soil containing less of these elements (a poor or thin soil); because on the latter the supply of mineral food is greater at that time, and is in the proportion of the ingredient, better fitted for the development of all parts of the plant, so far as its quantity extends.

Supposing we had given to our cultivated plants all the conditions essential to the assimilation of their atmospheric nutriment in the greatest abundance, the action of humus consists, according to the preceding application, in accelerating the development of the plant, in gaining time, an object of the highest value. In all cases, the produce of carbon is increased by the presence of humus, which, when the conditions essential to its conversion into other compounds are wanting, takes the form of starch, sugar, gum, &c.;

that is, of matters containing no mineral elements in their constitution. (This effect of the carbonic acid derived from humus, however, is not the only one; for, as already explained, it also acts as a solvent for the earthy phosphates and carbonates, probably its most important function in reference to our crops. See, in reference to this point, the note at p. 502.)

The element of time, in the art of agriculture, must always be taken into account; and, in this point of view, humus is of peculiar importance to the growth of garden vegetables.

When the cerealia, and plants grown for their roots, find, in our fields, in the remains of the preceding crop, a quantity of decaying vegetable substances corresponding to their amount of mineral nutriment from the soil, and consequently a quantity of carbonic acid adequate to their accelerated development in the spring, a further supply of carbonic acid, without a corresponding increase of mineral ingredients, is quite useless.

From a morgen of good meadow land, 2500 pounds weight of hay, according to the best agriculturists, are obtained on an average. This amount is furnished without any supply of organic substances, without manure containing carbon or nitrogen. By irrigation, and the application of ashes or gypsum, double that amount may be grown. But assuming 2500 pounds weight of hay to be the maximum, it is certain that all the carbon and nitrogen of these meadow crops is derived from the atmosphere.

According to Boussingault, hay, dried at a temperature of 100° Réaumur, contains 45·8 per cent. of carbon, and 1·5 per cent. of nitrogen. 14 per cent. of water retained by the hay, dried at common temperatures, is driven off at 100°. 2500 pounds weight of hay, therefore, corresponds to 2150 pounds dried at 100°. This shows us, that 984 pounds of carbon, and 32·2 pounds weight of nitrogen, have been obtained in the produce of one morgen of meadow land. Supposing that this nitrogen has been absorbed by the plants in the form of ammonia, the atmosphere contains 39·1 pounds weight of ammonia to every 3640 pounds weight of carbonic acid (= 984 carbon, or 27 per cent.); or, in other words, to every 1000 pounds weight of carbonic acid, $10\frac{7}{10}$ pounds of ammonia, that is, the ammonia thus taken up from the air forms about $\frac{1}{100,000}$ the weight of the air, or $\frac{1}{60,000}$ of its volume.

For every 100 parts of carbonic acid absorbed by the surface of the leaves, the plant receives from the atmosphere somewhat more than one part of ammonia.

If we calculate from the best analyses, how much nitrogen we obtain, in different crops, from the same surface of land, we obtain the following results:

For every 1000 pounds of carbon, we obtain—

From a meadow . .	$32\frac{7}{10}$	pounds	of nitrogen.
From cultivated fields,			
In Wheat .	21·5	”	”
Oats . .	22·3	”	”
Rye . .	15·2	”	”
Potatoes	34·1	”	”
Beetroot .	39·1	”	”
Clover .	44	”	”
Peas . .	62	”	”

Boussingault obtained from his farm at Bechelbronn, in Alsace, in five years, in the shape of potatoes, wheat, clover, turnips, and oats, 8383 lbs. of carbon, and 250·7 lbs. nitrogen. In the following five years, as beetroot, wheat, clover, wheat (winter), turnips, oats, and rye, 8192 lbs. of carbon, and 284·2 lbs. of nitrogen. In a further course of six years, potatoes, wheat, clover, wheat (winter), turnips, peas, and rye, 10,949 lbs. of carbon, 356·6 lbs. of nitrogen. In sixteen years, 27,424 lbs. carbon, 858·5 lbs. nitrogen, which gives for every 1000 carbon, 31·3 nitrogen.

From these interesting and unquestionable facts, we may deduce some conclusions of the highest importance in their application to agriculture.

1. We observe that the relative proportions of carbon and nitrogen, stand in a fixed relation to the surface of the leaves. Those plants, in which all the nitrogen may be said to be concentrated in the seeds, as the cerealia, contain on the whole less nitrogen than the leguminous plants, peas and clover.

2. The produce of nitrogen on a meadow which receives no nitrogenised manure, is greater than that of a field of wheat which has been manured.

3. The produce of nitrogen in clover and peas, which agriculturists will acknowledge require no nitrogenised manure, is far greater than that of a potato or turnip field, which is abundantly supplied with such manures.

Lastly. And this is the most curious deduction to be derived from the above facts,—if we plant potatoes, wheat, turnips, peas, and clover (plants containing potash, lime, and silex), upon the same land, three times richly manured, we gain in sixteen years, for a given quantity of carbon, the same proportion of nitrogen which we receive from a meadow which has received no nitrogenised manure.

On a morgen of meadow-land, we obtain in plants, containing silex, lime, and potash, 984 carbon, 32·2 nitrogen. On a morgen of cultivated land, in an average of sixteen years, in plants containing the same mineral elements, silex, lime, and potash, 857 carbon, 26·8 nitrogen.

If we add the carbon and nitrogen of the leaves of the beetroot, and the stalks and leaves of the potatoes, which have not been taken into account, it still remains evident that the cultivated fields, notwithstanding the supply of carbonaceous and nitrogenised manures, produced no more carbon and nitrogen than an equal surface of meadow-land *supplied only with mineral elements.*

What then is the rationale of the effect of manure,—of the solid and fluid excrements of animals?

This question can now be satisfactorily answered: that effect is the restoration of the elementary constituents of the soil which have been gradually drawn from it in the shape of grain and cattle. If the land I am speaking of had not been manured during those sixteen years, not more than one-half, or perhaps than one-third, part of the carbon and nitrogen would have been produced. We owe it to the animal excrements, that it equalled in production the meadow-land; but, with all the supply of this manure, the field became, in the sixth year, after being again manured, no richer in the mineral food of plants than it was in the first year. In the second year after manuring, it contained less than in the first, and in the fifth it was so much exhausted, that in order to obtain crops as good as at first, we had to restore as much mineral matter to the soil as we had removed in five years. This was unquestionably effected by the manure. But all that the supply of manure accomplished, was to prevent the land from becoming poorer in these, than the meadow which produced 2500 pounds of hay. We withdraw from the meadow in this hay as large an amount of mineral substances as we do in one harvest of grain, and we know that the fertility of the meadow is just as dependent upon the restoration of these ingredients to its soil, as the cultivated land is upon manures. Two meadows of equal surface, containing unequal quantities of inorganic elements of nourishment,—other conditions being equal,—are very unequally fertile; that which possesses most, furnishes most hay. If we do not restore to a meadow the elements withdrawn, its fertility decreases. But its fertility remains unimpaired, with a due supply of animal excrements, fluid and solid, and it not only remains the same, but may be increased by a supply of mineral substances alone, such as remain after the combustion of ligneous plants and other vegetables; namely, *ashes.* Ashes represent the whole nourishment which vegetables receive from the soil. By furnishing them in sufficient quantities to our meadows, we give to the plants growing on them the power of condensing and absorbing carbon and nitrogen by their surface. Must not, we ask, the effect of the solid and fluid excrements, *which are the ashes of plants and grains burned* in the bodies of animals and of man, be dependent upon the same cause? Must not the fertility, resulting from their application, be, to a certain extent, independent of the ammonia they contain? Would not their effect be precisely the same in promoting the fertility of cultivated plants, if we had evaporated the urine, and dried and burned the solid excrements, before adding them to the soil? Surely the cerealia and leguminous plants which we cultivate must derive their carbon and nitrogen from the same source whence the graminea and leguminous plants of the meadows obtain them! No doubt can be entertained of their capability to do so.

In Virginia, upon the lowest calculations, 22 pounds weight of nitrogen were taken on the average, yearly, from every morgen of the wheat-fields. This would amount, in 100 years, to 2200 pounds weight. If this were derived from the soil, every morgen of it must have contained hundreds of thousands of pounds weight of animal excrements (assuming the latter, when dried, at the temperature of boiling water, to contain 2 per cent. of nitrogen)!

In Hungary, as I remarked in a former Letter, tobacco and wheat have been grown upon the same land for centuries, without any supply of nitrogenised manure. Is it possible that the nitrogen essential to, and entering into, the composition of these crops, could have been drawn from the soil?

Every year renews the foliage and fruits of our forests of beech, oak, and chesnuts; the leaves, the acorns, the chesnuts, are rich in nitrogen; so are cocoa-nuts, bread-fruit, and other tropical productions. This nitrogen is not supplied by man. From a morgen of land, planted with mulberry trees, we raise in the form of silk-worms the nitrogen of the leaves on which they feed, and this crop is renewed annually, without the addition of any nitrogenised manure to the soil. It is impossible to entertain a doubt as to the origin of this nitrogen. Can it indeed be derived from any other source than the atmosphere?

In whatever *form* the nitrogen supplied to wild plants may be contained in the atmosphere, in whatever state it may be when absorbed, from the atmosphere it must have been derived. Must not the fields of Virginia and Hungary have received their nitrogen from the same source as wild plants?

Is the supply of nitrogen in the excrements of animals quite a matter of indifference, *or do we receive back from our fields a quantity of the elements of blood corresponding to the supply of ammonia thus given?*

The researches of Boussingault have solved this problem in the most satisfactory manner, and the more so, as his experiments were made for very different objects, and with different views. If, in his grand experiments, the manure which he gave to his fields were in the same state, *i. e.*, dried at 110° in a vacuum, as it was when analysed, these fields received, in sixteen years, 1300 pounds of nitrogen. But we know that by drying all the nitrogen escapes which is contained in solid animal excrements, as volatile carbonate of ammonia. In this calculation the nitrogen of the urine, which by decomposition is converted into carbonate of ammonia, has not been included. If we suppose it amounted to half as much as that in the dried excrements, this would make the quantity of nitrogen supplied to the fields, in sixteen years, 1950 pounds.

In sixteen years, however, as we have seen, only 1517 pounds of nitrogen were contained in their produce of grain, straw, roots, &c.—that is, *far less* than was supplied in the manure; and in the same period the same surface of good meadow land (one hectare = 4 Hessian morgens), which received no nitrogen in manure, yielded 2060 pounds of nitrogen.

It is well known, that in Egypt, from the deficiency of wood, the excrement of animals is dried, and forms the principal fuel, and that the nitrogen from the soot of this excrement was, for many centuries, imported into Europe in the form of sal-ammoniac, until a method of manufacturing this substance was discovered at the end of last century by Gravenhorst, of Brunswick. The fields in the delta of the Nile are supplied with no other animal manure than the ashes of the burnt excrements, and yet they have been proverbially fertile from a period earlier than the first dawn of history, and that fertility continues to the present day as admirable as it was in the earliest times. These fields receive every year, from the inundation of the Nile, a new soil, in its mud deposited over their surface, rich in those mineral elements which have been withdrawn by the crops of the previous harvest. The mud of the Nile contains as little nitrogen as the mud derived from the Alps of Switzerland, which fertilises our fields after the inundations of the Rhine. If this fertilising mud owed this property to nitrogenised matters, what enormous beds of animal and vegetable exuviæ and remains ought to exist in the mountains of Africa, in heights extending beyond the limits of perpetual snow, where no bird, no animal finds food, from the absence of all vegetation!

Abundant evidence in support of the important truth we are discussing may be derived from other well-known facts. Thus, the trade of Holland in cheese may be adduced in proof and illustration thereof. We know that cheese is derived from the plants which serve as food for cows. The meadow-lands of Holland derive the nitrogen of cheese from the same source as with us; *i. e.* the atmosphere. The milch cows of Holland remain day and night on the grazing-grounds, and therefore, in their fluid and solid excrements return directly to the soil all the salts and earthy elements of their food: a very insignificant quantity only is exported in the cheese. The fertility of these meadows can, therefore, be as little impaired as our own fields, to which we restore all the elements of the soil, as manure, which have been withdrawn in the crops. The only difference is, in Holland they remain on the field, whilst we collect them at home, and carry them from time to time to the fields.

The nitrogen of the fluid and solid excrements of cows is derived from the meadow-plants, which receive it from the atmosphere; the nitrogen of the cheese also must be drawn from the same source. The meadows of Holland have, in the lapse of centuries, produced millions of hundredweights of cheese. Thousands of hundredweights are annually exported, and yet the productiveness of the meadows is in no way diminished, although they never receive more nitrogen than they originally contained.

Nothing can be more certain than the fact, that an exportation of nitrogenised products does not exhaust the fertility of a country; inasmuch as it is not the soil, but the atmosphere, which furnishes its vegetation with nitrogen. It follows, consequently, that we cannot increase the fertility of our fields by a supply of nitrogenised products, or by *salts of ammonia, alone*, but rather that their produce increases or diminishes, in a direct ratio, with the supply of mineral elements capable of assimilation. The formation of the constituent elements of blood, that is, of the nitrogenised principles in our cultivated plants, depends upon the presence of inorganic matters in the soil, without which no nitrogen can be assimilated even when there is a most abundant supply. The ammonia contained in animal excrements exercises a favourable effect, inasmuch as it is accompanied by the other substances necessary to accomplish its transition into the elements of blood. If we supply, along with the ammonia, all the conditions necessary to its assimilation, it ministers to the nourishment of the plants; but if this artificial supply of ammonia is not given they can derive all the required nitrogen from the atmosphere —a source, every loss from which is restored by the decomposition of the bodies of dead animals and the decay of plants. Ammonia certainly favours and accelerates the growth of plants in all soils, wherein all the conditions of its assimilation are united ; but it is altogether without effect, as respects the production of the elements of blood, where any of these conditions are wanting. We can suppose that *asparagine,* the active constituent of *asparagus* and of the mucilaginous root of the *marsh-mallow,* the nitrogenised and sulphurous ingredients of *mustard-seed,* and of all cruciferous plants, may originate without the aid of the mineral elements of the soil. But if the principles of those vegetables which serve as food could be generated without the co-operation of the mineral elements of blood, without potash, soda, phosphate of soda, phosphate of lime, they would be useless to us and to herbivorous animals as food; they would not fulfil the purpose for which the wisdom of the Creator has destined them. In the absence of alkalies and the phosphates, no blood, no milk, no muscular fibre can be formed. Without phosphate of lime we might perhaps have horses, sheep, and cattle, but they would be without bones.

In the urine and in the solid excrements of animals, and in guano, we give ammonia, and consequently nitrogen, to our cultivated plants, and this nitrogen is accompanied by all the mineral elements of food exactly in the same proportions in which both are contained in the plants which served as food to the animals, or what is the same, in those proportions in which they can serve as nourishment to a new generation of plants, to which both are essential.

The effect of an artificial supply of ammonia, as a source of nitrogen, is, therefore, precisely analogous to that of humus as a source of carbonic acid—it is limited to a *gain of time;* that is, it accelerates the development of cultivated plants. Ammonia, when added in the form of excrements of man and animals, increases the proportion of sanguinigenous matter in our crops, an effect which the carbonate and sulphate of ammonia alone would never produce.

In order to avoid all misunderstanding, I must again point out that the preceding explanation is in no respect inconsistent with the good effects of an artificial supply of ammonia or ammoniacal salts. Ammonia continues to be the source of all the nitrogen of plants; a supply of it is always beneficial, and, for certain objects, indispensable; but it is of the utmost importance for agriculture, to know with certainty that the supply of ammonia is, for many of our cultivated plants, unnecessary and superfluous; and that the value of a manure, as is the established rule in France and Germany, cannot be judged of by the proportion of nitrogen it contains, and is not proportional to the amount of nitrogen. If the mineral elements, phosphates, &c., be duly supplied, the plant will obtain a sufficient supply of ammonia from the atmosphere. If these be absent, or deficient in quantity, the greatest artificial supply of ammonia will do no good, and will be a pure loss to the farmer.

When we have exactly ascertained the quantity of ashes left after the combustion of cultivated plants which have grown upon all varieties of soil, and have obtained correct analyses of these ashes, we shall learn with certainty which of the constituent elements of the plants are constant and which are variable, and we shall arrive at an exact knowledge of the sum of all the ingredients we withdraw from the soil in the different crops.

With this knowledge the farmer will be able to keep an exact record, of the produce of his fields in harvest, like the account-book of a well-regulated manufactory; and then by a simple calculation he can determine precisely the substances he must supply to each field, according to the crops he has reaped, and the quantity of these, in order to restore their original fertility. He will be able to express, in pounds weight, how much of this or that element he must give to the soil in order to augment its fertility for any given kind of plants.

These researches and experiments are the great *desideratum* of the present time. TO THE UNITED EFFORTS OF THE CHEMISTS OF ALL COUNTRIES WE MAY CONFIDENTLY LOOK FOR A SOLUTION OF THESE GREAT QUESTIONS, and by the aid of ENLIGHTENED AGRICULTURISTS we shall arrive at a RATIONAL system of HORTICULTURE, and AGRICULTURE, applicable to every country and all kinds of soil, and which will be based upon the immutable foundation of OBSERVED FACTS and PHILOSOPHICAL INDUCTION.

LETTER XXXV.

My researches into the constituent ingredients of our cultivated fields have led me to the conclusion that, of all the elements furnished to plants by the soil and ministering to their nourishment, the phosphate of lime—or, rather, the phosphates generally—must be regarded as the most important.

In order to furnish you with a clear idea of the importance of the phosphates, it may be sufficient to remind you of the fact, that the blood of man and animals, besides common salt, always contains alkaline and earthy phosphates. If we burn blood and examine the ashes which remain, we find certain parts of them soluble in water, and others insoluble. The soluble parts are, common salt and alkaline phosphates; the insoluble consist of phosphate of lime, phosphate of magnesia, and oxide of iron.

These mineral ingredients of the blood—without the presence of which in the food the formation of blood is impossible—both man and animals derive either immediately, or mediately through other animals, from vegetable substances used as food; they had been constituents of vegetables, they had been parts of the soil upon which the vegetable substances were developed.

If we compare the amount of the phosphates in different vegetable substances with each other, we discover a great variety, whilst there is scarcely any ashes of plants altogether devoid of them, and those parts of plants which experience has taught us are the most nutritious, contain the largest proportion.

To these belong all seeds and grain, especially the varieties of bread-corn, peas, beans, and lentils.

It is a most curious fact that if we incinerate grain or its flour, peas, beans, and lentils, we obtain ashes, which are distinguished from the ashes of all other parts of vegetables by the absence of *alkaline carbonates.* The ashes of these seeds when recently prepared, do not effervesce with acids; their soluble ingredients consist solely of alkaline phosphates, the insoluble parts of phosphate of lime, phosphate of magnesia, and oxide of iron: consequently, of the very same salts which are contained in blood, and which are absolutely indispensable to its formation. We are thus brought to the further indisputable conclusion that no seed suitable to become food for man and animals can be formed in any plant without the presence and co-operation of the phosphates. A field in which phosphate of lime, or the alkaline phosphates, form no part of the soil, is totally incapable of producing grain, peas, or beans.

An enormous quantity of these substances indispensable to the nourishment of plants, is annually withdrawn from the soil and carried into great towns, in the shape of flour, cattle, et cetera. It is certain that this incessant removal of the phosphates must tend to exhaust the land and diminish its capability of producing grain. The fields of Great Britain are in a state of progressive exhaustion from this cause, as is proved by the rapid extension of the cultivation of turnips and mangel wurzel—plants which contain the least amount of the phosphates, and therefore require the smallest quantity for their development. These roots contain 80° to 92° per cent. of water. Their great bulk makes the amount of produce fallacious, as respects their adaptation to the food of animals, inasmuch as their contents of the ingredients of the blood, *i. e.* of substances which can be transformed into flesh, stands in a direct ratio to their amount of phosphates, without which neither blood nor flesh can be formed.

Our fields will become more and more deficient in these essential ingredients of food, in all localities where custom and habits do not admit the collection of the fluid and solid excrements of man, and their application to the purposes of agriculture. In a former letter I showed you how great a waste of phosphates is unavoidable in England, and referred to the well-known fact that the importation of bones restored in a most admirable manner the fertility of the fields exhausted from this cause. In the year 1827 the importation of bones for manure amounted to 40,000 tons, and Huskisson estimated their value to be from 100,000*l.* to 200,000*l.* sterling. The importation is still greater at present, but it is far from being sufficient to supply the waste.

Another proof of the efficacy of the phosphates in restoring fertility to exhausted land is afforded by the use of the *guano*—a manure which, although of recent introduction into England, has found such general and extensive application

We believe that the importation of one hundred-weight of *guano* is equivalent to the importation of eight hundred-weight of wheat—the hundred-weight of guano assumes in a time which can be accurately estimated the form of a quantity of food corresponding to eight hundred-weight of wheat. The same estimate is applicable in the valuation of bones.

If it were possible to restore to the soil of England and Scotland the phosphates which during the last fifty years have been carried to the sea by the Thames and the Clyde, it would be equivalent to manuring with millions of hundred-weights of bones, and the produce of the land would increase one-third, or perhaps double itself, in five to ten years.

We cannot doubt that the same result would follow if the price of the guano admitted the application of a quantity to the surface of the fields, containing as much of the phosphates as have been withdrawn from them in the same period.

If a rich and cheap source of phosphate of lime and the alkaline phosphates were open to England, there can be no question that the importation of foreign corn might be altogether dispensed with after a short time. For these materials England is at present dependent upon foreign countries, and the high price of guano and of bones prevents their general application, and in sufficient quantity. Every year the trade in these substances must decrease, or their price will rise as the demand for them increases.

According to these premises, it cannot be disputed, that the annual expense of Great Britain for the importation of bones and guano is equivalent to a duty on corn: with this difference only, that the amount is paid to foreigners in money.

To restore the disturbed equilibrium of constitution to the soil,—to fertilise her fields,—England requires an enormous supply of animal excrements, and it must, therefore, excite considerable interest to learn, that she possesses beneath her soil, beds of fossil *guano*, strata of animal excrements, in a state which will probably allow of their being employed as a manure at a very small expense. The coprolithes discovered by Dr. Buckland, (a discovery of the highest interest to Geology,) are these excrements; and it seems extremely probable that in these strata England possesses the means of supplying the place of recent bones, and therefore the principal conditions of improving agriculture—of restoring and exalting the fertility of her fields.

In the autumn of 1842, Dr. Buckland pointed out to me a bed of coprolithes in the neighbourhood of Clifton, from half to one foot thick, inclosed in a limestone formation, extending as a brown stripe in the rocks, for miles along the banks of the Severn. The limestone marl of Lyme Regis consists, for the most part, of one fourth part of fossil excrements and bones. The same are abundant in the lias of Bath, Eastern and Broadway Hill, near Evesham. Dr. Buckland mentions beds, several miles in extent, the substance of which consists, in many places, of a fourth part of coprolithes.

Pieces of the limestone rock of Clifton, near Bristol, which is rich in coprolithes and organic remains, fragments of bones, teeth, &c., were subjected to analysis, and were found to contain above 18 per cent. of phosphate of lime. If this limestone is burned and brought in that state to the fields, it must be a perfect substitute for bones, the efficacy of which as a manure does not depend, as has been generally, but erroneously supposed, upon the nitrogenised matter which they contain, but on their phosphate of lime.

The osseous breccia found in many parts of England deserves especial attention, as it is highly probable that in a short time it will become an important article of commerce.

What a curious and interesting subject for contemplation! In the remains of an extinct *animal* world, England is to find the means of increasing her wealth in agricultural produce, as she has already found the great support of her manufacturing industry in fossil fuel,—the preserved matter of primeval forests,—the remains of a *vegetable* world. May this expectation be realised! and may her excellent population be thus redeemed from poverty and misery!

APPENDIX.

No. 1.—History of the Boy with the Golden Tooth.—(Sprengel, vol. iii., 403—406. Sixteenth year.) *To page* 54.

"A boy, ten years old, in the neighbourhood of Schweidnitz, was the miraculous child, in whom had grown this golden tooth. Jacob Horst, formerly physician in Schweidnitz, heard in Helmstadt, where he was at that time (1595) professor, of this history, and wrote a very strange book about it; where, without for a moment doubting the authenticity of the story, he at once regards the production of this tooth as a supernatural event, depending on the constellation under which the boy was born. On the day of his birth (22nd December, 1586), says Horst, the sun had been in the sign of Aries. By this supernatural cause, the nutritive force, in consequence of the increased heat, had been miraculously augmented, and thus, instead of bone, gold had been secreted. He then proceeds to examine the significance of this miracle, as a sign of future events. As every eclipse and every earthquake has its prophetic meaning, so also this tooth must be regarded as a sign of the golden age. The Emperor would expel the Turks, those enemies of Christendom, from Europe, and then the millennium and the golden age would be at hand. To establish this prophecy, Horst refers to Daniel (chap. ii.) where the golden head of the image signifies a great empire. But because the golden tooth was the latest in the jaw of the Silesian boy, so also would this firmly established authority of the Roman Emperor go to judgment shortly before the coming of Christ."

"Two other physicians, Martin Ruland the younger of Lauingen, at that time in Ratisbon, whence he subsequently went to Prague, and John Ingolstetter of Nuremberg, who was also Pro-rector of the Paedagogium at Amberg, disputed, not about the fact, for both appear to have been convinced of it, but about the theory of this occurrence. The former had tried to explain it by natural causes; but the latter, if we may judge from the title of his book, endeavoured to prove that it was a true miracle, or supernatural event. Duncan Liddel, a Scotchman, wrote a successful refutation of the chimæra of Horst. Balthazar Cammæus had already remarked, at the end of 1595, that the miraculous boy no longer allowed himself to be examined by learned men, but became almost furious when attempts were made to force him to submit to examination; and that it was, therefore, suspected that the famous tooth was only covered with gold leaf; for the root of this tooth certainly could not be gold."

No. 2.—Extracts from the Letter of Galileo to Madama Cristina, Granduchessa Madre. *Page* 59.

"We bring forward that which is new, not to confuse nature nor the minds of men, but to enlighten them; not to destroy science, but to give it a true foundation. But our opponents call false and heretical, that which they cannot refute, making for themselves a shield of simulated zeal for religion, and degrading the Holy Scriptures into the instrument of private ends. But a writer ought not to be condemned unheard, when he treats not of ecclesiastical, but of natural things, and does so with the aid of reasons derived from astronomy and geometry. He who would hold in all cases to the naked grammatical sense, must needs accuse the Bible of contradictions, nay, of blasphemies, when it speaks of God's eye, his hand, or his anger. And if this take place in the apprehension of the people, how much the more ought we to regard it, in matters which are remote from the observation of the many, and do not affect our salvation, as the natural sciences. In these, therefore, we must not begin with the authority of the Bible, but with the observations of our senses, and the necessary proofs, because nature and the Bible alike owe their existence to God. As the Bible, to accommodate itself to the ignorance of men, says many things figuratively, while nature, immutable and inexorable, never steps beyond the letter of her laws, not caring whether her concealed causes and modes of action be adapted to the comprehensions of men; it appears, that that which observation and evidence bring before our eyes and intellects ought by no means to be brought into doubt by texts of scripture, which have a double sense, because each word is not bound by such strict rules, as are natural phenomena, and God reveals himself in the latter not less gloriously than in the words of the Bible. Before all things, therefore, we must make sure of facts. To these the Bible cannot be opposed, else would God contradict himself; we must consequently expound their sense accordingly, and the capacity of making such researches is also a gift of God. For astronomy we have received sense and understanding; but the Bible in this respect, speaks as the people then regarded the matter, for the people was not to be alarmed, and if the Bible had given rest to the sun, and motion to the earth, the feeble understanding of the people would have been confused, and they would have become perverse and obstinate in the belief of the principles of religion. But where has the Bible condemned the new doctrine? The Holy Spirit has been silent on this head, and if, therefore, our views have nothing to do with our salvation, how can they be heretical? The Holy Spirit has taught how we are to reach Heaven, not how heaven moves. It is setting the reputation of the Bible on a hazard, to view the matter otherwise, and, as our opponents do, instead of expounding scripture according to facts surely proved, rather to force nature, to deny experiment, to despise the intellect. Neither is it any rash or reckless thing, if any man should not adhere to antiquity. But to found geometry on the Bible shows a false notion of its supreme dignity, as absurd as it would for a king, because he is a king, to insist on being physician and architect to his subjects, and force them to use his prescriptions.

"It is not in the power of the man of science to alter his opinions, to turn them this way and that; he cannot be commanded; he must be convinced. To cause our doctrine to disappear from the world, it is not enough to shut the mouth of a man, as those imagine, who measure the judgment of others by their own. It would be necessary not merely to prohibit a book, and the writings of the adherents of the doctrine, but to prohibit all science; to forbid men to look towards the heavens, in order that they should see nothing that does not fit with the old system, while it is explained by the new. It is a crime against truth, when men seek the more to suppress her, the more clearly and openly she shows herself. But to condemn one opinion and leave the rest standing, would be still worse, for it would give men the chance of seeing an opinion proved to be true, which had been condemned as false. But to forbid science itself, would be against the Bible, which teaches in a hundred places, how the greatness and glory of God are wonderfully seen in all his works, and are to be read in their full divinity in the open book of the heavens. And let none believe that we have completed the reading of the sublime thoughts which stand written in characters of light on those pages, when we have gazed at the brightness of the sun and stars at their rising and setting, which, indeed, the beasts also can do; but there are therein mysteries so profound, ideas so sublime, that the nightly labours, the observations, the studies of hundreds of the acutest minds, after a thousand years of research have not yet fully penetrated them, but the pleasure of investigation and discovery endures eternally."—(From M. Carrière's Weltauschanung, p. 138—184.)

No. 3.—*To page* 229.

"In the lying-in hospital here (Vienna) since there has been a division for the instruction of physicians, and a division for midwives, the number of deaths on the physicians' side was constantly greater, in 1846 even four times greater, than on that of the midwives.

"It is easy to understand that so enormous a difference in the mortality in two parts of the same hospital (in 1846, for an equal number of puerperal cases the *excess* of deaths on the physicians' side was 400) attracted universal attention, and that attempts were made to detect its cause. . . . After Dr. Semmelweis, assistant on the physicians' division, had for several months considered all the circumstances, he recognised in the fact, that both he and the students occupied themselves frequently with *post-mortem* examinations; that the cadaverous smell on their hands, in spite of repeated washing, does not disappear till after a considerable time, and that the pupils not unfrequently proceed to the examination of women in labour immediately after dissecting a dead body, the only possible mode by which a putrescent animal substance could be conveyed to the genitals of the puerperal patients, (which had been ascertained to be one of the proximate causes of the disease, of the formation of purulent matter in the blood, and in the present instance had been kept in view by Dr. S.) This was also the only one of the probable causes of puerperal disease, which either did not occur at all, or occurred only in a very limited degree, in the midwives' division.

"Dr. Semmelweis now adopted the rule, that every one, before examining a patient, should wash their hands with chlorine water.

"When this rule was adopted, the patients on the physicians' side were not more frequently attacked by puerperal disease than those of the midwives.

"In 1848, of 3780 cases delivered on the physicians' side

45 died, or 1·19 per cent.; while on that of the midwives, of 3219 cases, 43 died, or 1·33 per cent. During the three years that washing with chlorine water has been used, the deaths on the two sides have been equal."

(From a lecture by Professor Skoda, at the meeting of the Imperial Academy at Vienna, on the 18th of October, 1849, from which moreover it appears how small is the recognition which this great and practically important discovery has met with beyond the Academy. No doubt several causes of puerperal fever might be named, but no impartial person can doubt that this cause, discovered in the Lying-in Hospital at Vienna, by Dr. Semmelweis, with all the acuteness of an unprejudiced philosopher, is one of them.)

No. 4.—*To page* 229.

"In order to procure a roast for Easter," says Dr. Röser, "C—— in R—— desired his family to set a snare for a roebuck. Accordingly, one of these poor animals was caught in the snare, which, as its head and breast had passed through, held it by the hinder part of the body, the abdomen and pelvis being inclosed in the cord, so that it must have succumbed after a most agonising struggle. It was found next day dead.

"The master and mistress of the family eat, on Easter day, the best part of this dainty; the servants had little; the remainder was laid in vinegar, but not eaten.

"On the same day all in the family who had eaten of the venison observed a striking dryness of the mouth, oppression at the stomach, and nausea; the features in all became anxious and pale; all complained of oppression of the head, giddiness, and great weariness of the limbs. The master lost his sight for several days, and in short there now began a series of remarkable symptoms, requiring in many ways the assistance of Dr. Röser. The husband was only restored to health in July, but the wife never recovered; she lingered more than two years, and at last died after severe sufferings. The daughter, the man-servant, and the maid, who had eaten little of the tortured animal, were soon cured. The symptoms in many respects recalled those of the effects of the bite of rabid animals (and of the sausage poison of Wirtemberg?)" Dr. Röser concludes his communication in these words:— "Many an animal (for example in hunting) is tortured to death in the most barbarous manner, like the roe-deer in the snare. Ought not then the medical police to be led, by cases like this, to adopt the strictest regulations to prevent the use, as food, of animals which have been in any way tortured to death, and to insure that the animals intended for food are not tortured before being slaughtered?"—(Dr. C. G. Carus. From the periodical "Der Menschenfreund in seinen beziehungen zur belebten Welt." A popular paper, published by the Dresden Society for the protection of Animals.)

No. 5.—*To page* 230.

The construction of the railway from Strasburg to Basle, rendered it necessary, at many points, to excavate the fields bordering the line to the depth of 1 to 2 metres (3¼ to 6½ feet), to obtain earth for the mounds of dykes supporting the railway. This caused hollows extending to 13 or 14 hectares, (40 or 50 acres) in size, and on a length of 3 kilometres (5 or 6 miles), in the neighbourhood of the communes of Bollweiler and Feldkirch. In spring and autumn these hollows fill with water, which in summer partially dries up, and leaves a mud, very injurious to health. They have thus become true morasses, in which Herr A. Baumann found those plants which are peculiar to stagnant water, as *Polygonum hydropiper*, *Arundo phragmites*, *Alisma plantago*, &c., &c.

Under the influence of these dangerous swamps the commune of Bollweiler, which has 1446 inhabitants, has been, for the last three years, most cruelly visited by intermittent fever. The following statement, confirmed by the Burgomaster, Herr Durwell, proves that the evil, instead of diminishing, has become yearly greater. The following table gives the number of persons attacked with intermittents during the four years.

In the year 1843	36
„ „ 1844	166
„ „ 1845	743
„ „ 1846	1166

The mortality has increased in the same proportion. The average mortality of ten years (1836 to 1845, including therefore some of the worst years of the intermittent fever,) is 36. In 1836 the deaths amounted to 54. In the same period, the days lost to the people in consequence of their inability to work, the fees of physicians, and the expense of medicines, amounted to 116,515 francs.

The little commune of Feldkirch, with only 480 inhabitants, suffered no less severely. The following is the account, confirmed by the Burgomaster of the cases of intermittent fever in the four preceding years.

In the year 1843	2
„ „ 1844	20
„ „ 1345	135
„ „ 1846	376

The annual mortality rose from 11 to 18. The loss of work and the cost of illness amounted to 42,219 francs. To these facts, Drs. Weber, Sänger, and West, the authors of a very decisive report to the prefect of the Upper Rhine, add others, which are not less conclusive. The apothecary Larger, in Soultz, the chief town of the three cantons affected by this plague, sold the following quantities of sulphate of quinine:—

In the year 1843	120 grammes
„ „ 1844	150 „
„ „ 1845	970 „ .

"The state can no longer remain unconcerned and inactive in face of so great an evil. Three years, full of suffering, have entirely prostrated the unfortunate inhabitants of Bollweiler and Feldkirch, and the writer of this letter, Dr. Dollfus-Ausset, turns to the Academy, that their knowledge may instruct the administration concerning the best means of checking the plague which has decimated two villages, and threatens others."—(Comptes rendus de l'Académie de Sciences à Paris, Séance du 5 Mar. 1847, p. 779. In the sitting of the 24th of May, M. Sainte-Preuve proposed, as undoubtedly the best means of putting an end to this source of disease, to connect the hollows with running water, and thus cause the stagnant water to circulate.)

No. 6.—*To page* 454.

"The voice of the people has embodied in a merry tale the genial disposition of the jovial Rhinelander. Nowhere," so runs the story, "do men so rarely lay violent hands on themselves as on the banks of the Rhine. It is especially an unheard-of event in the chronicles of that valley, that a man, tired of life, ever selected the mode of suicide by hanging, which is characteristic of the gloomiest melancholy. There was only one man in the Rhine valley who ever wished to hang himself. All his goods and gear were gone, he had pledged the last of his furniture for debt, and his creditors had left nothing but half a cask of wine in the cellar. Then the man went to the garret, took a new rope, rubbed it with oil, that it might run smoothly, twisted a most artistical noose, and placed himself under a cross-beam. But, as he was on the point of taking the eventful journey, the half cask of wine in the cellar came into his mind. Only one draught to help him on the road! He considered long; but he stole down, took the spigot, and inserted it at the bung-hole, where the best liquor, the noblest heart's blood of the cask, is always found, and drew a single pint. And when he had drained that, he found that the wine was good, and took a second. At the third measure he thought how foolish it would be to leave so large a legacy of the good wine to his laughing heirs; so he turned down a fourth. But when he had reached the seventh pint, he gently raised the bung, took the new, oiled rope, threw it into the cask, and cried; 'Drown thyself, cursed rope! I will first drain the cask to the dregs, and then we shall see what is to be made of thee.' But when the man, some time after, had drunk out the cask, he found that the rope was no longer fit for use. That was the only man of the Rhine, who ever wished to hang himself.

"For the last thousand years the life of the Rhinelander is, as it were, steeped in wine; he has become, like good old wine casks, tinted with the vinous green. This gives him his originality. For there are many wine countries in Germany, but none where, as in the Rhinegau, wine is everything. Wine is the creed of the Rhinelander in everything. As in England, in the days of Cromwell, the royalists were known by their meat pasties, the papists by their raisin soup, the atheists by their roast beef, so is the man of the Rhinegau known, time immemorial, by his wine-flask.

"In the Rhinegau they tell of mothers, who gave their newborn children, as their first nourishment, a spoonful of good old wine, as if to impress on them in the cradle the stamp of their native home. A valiant 'Brenner' (burner), as on the Rhine they call the thorough jolly companion, drinks every day his seven bottles of wine, and with it grows as old as Methuselah, is seldom drunk, and has at most the Bardolph mark of a red nose. The characteristic heads of the seasoned winebibbers, of the hairsplitting connoisseurs in wine, who, however, are one and all unable, with wine-bandaged eyes, to tell red from white by taste alone; of the prophets, of the sample-hunters, the men who travel from one sale of wine to another, and drink their fill, gratis, of the samples; are nowhere to be seen in an originality so fresh as in the Rhinegau. All these physiognomies, in their infinite varieties, when collected and framed at a wine-tasting, appear like the sailors' taverns among the old Dutch, likely to become a standing theme for our modern painters of character.

"The chronology of the natives of the Rhinegau is not calculated on calendar years, but on wine years. Unfortunately their usual reckoning, from one distinguished vintage to another, agrees pretty nearly with the Greek system of Olympiads. The whole speech of the Rhinelander is embroidered with original expressions, which point to the culture of the vine. They would fill a lexicon. Several of the customary words of praise applied to wine, are a poem from the peoples' lips, condensed into one word. Thus it is prettily said of a right harmonious noble liquor of the last year, 'There is music in that wine.' A good old wine is a 'Chrysam,' a consecrated oil. The 'flower,' (Blume) or 'bouquet' of wine have already become, from local expression, terms universally employed. The Rhinelander is as rich in such splendid poetical names for his wine as the Arab is in poetical epithets for his noble steed. In the middle ages the inferior, sour wine, 'the quart whereof was scarce three farthings worth,' was called on the Rhine 'Councillor;' but hardly for the innocent reason given by a late chancellor, when he says, 'for, however much of it one might drink, it left a man his full understanding, as all councillors should be men of understanding.' Poetically figurative is the modern name of 'Dreimânnerverein' (association of three men,) given in the Rheingau to a wine which can only be drunk thus: two men hold the drinker fast, while the third pours the noble liquor down his throat. As expressive, musically, sounds the grumbling word 'Rambass,' for a rough, coarse, tasteless, blunderer among wines. The 'Groschenburger'(penny wine) of the Rheingau, corresponds to the 'Batzenwein' (also penny wine) of Upper Germany.

"The Rhinegau has even its own 'wine saints.' First, St. Goar, whose cask, a gift from the Emperor Charlemagne, always filled itself, and who loaded with gifts those guests who, provided they had previously undergone baptism with water, desired also from him the baptism of wine. The legend of St. Theonest, the patron saint of Caub, who underwent his martyrdom at Mainz, then floated down the river through the whole Rhinegau in a dainty wine-tub, and at length landed alive at Caub, where he planted the first vines, contains one of the plainest and most intelligible symbolisations of all the sufferings or tortures which the grape has to undergo before, rising from the bands of death in the fermenting tub, it is glorified or transfigured into the golden wine.

"When the North German porter groans under a heavy burden, and is compelled, in order to advance at all, to set it down at short intervals, he strengthens himself for each new effort by a hearty curse, which never fails to help him. But when the Rhenish coopers have to carry up out of the cellar a heavy cask, which they must take up again after every pause, then they strengthen themselves for each new attempt by a hearty draught of wine, and this, too, never fails. Not less inexhaustible than the poetry of the vineyard, but as yet little studied, is the poetry of the wine-vault or cellar. Not alone have the castle of Johannisberg and the convent of Eberbach their wines stored in splendid vaults, where the double gleam of the broken daylight and the glimmer of lamps is so majestically reflected from the vaulted roof, while heavy buttresses cast their gigantic shadows between; the same is seen, on a smaller scale, in hundreds of old private cellars, magnificent subterraneous buildings of their kind. When in early winter the cellars are filled with the stupefying vapours of the fermenting new wine, then, when it is necessary to descend, firebrands are pushed down from one flight of the cellar stairs to another, and while through the dark depths the harsh lights flash, men can go down gradually to the casks under the protection of the purifying flame. When in spring the Rhine flood unexpectedly rises into the well-stored cellars, the coopers often sail about in them in wine tubs, like St. Theonest, to fix the casks to the ground, in order that they may not be carried away. But they cannot always keep above water so skilfully as the saint, and this causes the most laughable adventures."—(Supplement to the Augsburg Allemeine Zeitung: 18th November, 1850.)

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